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Final Technical Report

August 1999

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Truck-in-the-Park

Biodiesel Demonstration with Yellowstone National Park

Final Technical Report

August 1999

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ABSTRACT

The "Truck in the Park" project is a jointly funded research project which demonstrates the benefits of using biodiesel in a tourism related industry. The National Park Service (NPS) has operated a truck in Yellowstone National Park (YNP) for 149,408 km (92,838 miles) on 100 percent biodiesel fuel produced by the University of Idaho. The main focus of the project was to demonstrate the reliability, benefits, and costs of using biodiesel to NPS, tourism operators, and potential fuel producers. Participants in this project included the Montana Department of Environmental Quality (DEQ), Wyoming Department of Commerce, NPS, Department of Energy's Pacific Northwest and Alaska Regional Biomass Energy Program, Koch Agri-Services, J.R. Simplot Company, Dodge Truck, Cummins Engine Company and their Intermountain Distributors, Western States Caterpillar, University of California at Davis, and the University of Idaho.

This is the final technical report for the Truck-in-the-Park project. It details the fuel production and quality control, engine performance and durability, and engine emissions tests performed on the test vehicle.

The test vehicle was a 1995 Dodge 2500 four-wheel drive pickup with a 5.9 liter Cummins B series, turbocharged, and intercooled, direct injected diesel engine. NPS operated the truck in Yellowstone National Park for 149,408 km (92,838 miles). The engine examination at 92,838 miles was done to evaluate impacts on emissions resulting from the fuel because the miles completed was much less than the life to overhaul this engine. The truck ran on a Canola Ethyl Ester (CEE) and Rapeseed Ethyl Ester (REE) biodiesel made with ethanol from waste potatoes. The fuel was delivered to NPS in lots of about 3000-3800 liters (800-1000 gallons) and stored in a 37,850 liter (10,000 gallon) storage tank at Yellowstone National Park. A total of

23,076 liters (6,096 gallons) of fuel was delivered over the course of the project. Each batch of fuel delivered to the Park Service was analyzed by the University of Idaho for quality and consistency.

Chassis dynamometer tests were performed at regular intervals on the truck. These tests showed that the vehicle did not experience a reduction in power over time. Oil analysis, compression, injector tests, and engine and fuel pump teardown inspections also indicate that the engine did not experience excessive wear or deterioration as a result of using the biodiesel as a fuel. The durability was considered equivalent or better than that normally achieved with conventional 2-D diesel fuel.

The truck was emissions tested at the Los Angeles Metropolitan Transit Authority Emissions Testing Facility at the beginning (March 1995) and end (May 1998) of the project. Results from these tests indicated HC and CO decreased and PM increased as the percentage of Rapeseed Ethel Ester biodiesel was increased. NOx generally decreased as the percentage of REE was increased. Fuel consumption for the same amount of work increased by 14 percent from 1995 to 1998. The increase in fuel consumption was consistent with the increase of CO2 emissions between 1995 and 1998 for the same fuels. Cold start data were limited, but they show that HC, CO, and PM increased more for cold starts with 2-D diesel fuel than for cold starts with REE compared to hot starts with the same fuel. Results show that nearly 161,000 km (100,000 miles) of use with 100 percent CEE did not affect the efficiency of the catalytic converter.

ACKNOWLEDGEMENTS

The author wishes to acknowledge Howard Haines of the Montana Department of Environmental Quality for finding initial financial support and asking the University of Idaho to be involved in the "Truck in the Park," project, and to Craig Chase, a consultant to DOE and the Pacific Northwest and Alaska Regional Bioenergy Program for his encouragement during this work. The author also wishes to acknowledge the cooperation of Lauren Dunlap, Ray Wilson, Kwesi Annan and Harvey Porter at the LA-MTA who actually conducted the emissions tests, and to Jack Roberts and Jim Evanoff of the National Park Service for the truck's operation and maintenance at Yellowstone National Park.

The author also wishes to acknowledge all the members of his committee and especially Dr. Charles Peterson for his support, patience and invaluable insight.

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1 INTRODUCTION

Each year, about 3 million people visit Yellowstone National Park (YNP). Over 900,000 automobiles burn thousands of gallons of fuel and produce tons of air pollutants inside the park. With visitation increasing steadily over the last several decades, the National Park Service (NPS) is concerned about the increased vehicular congestion and the threat of increased pollution. NPS is exploring ways to protect the pristine environment of YNP from the increase in vehicle pollution while not detracting from the visitor's experience. Limiting the amount of people allowed to visit the park is a possible solution, but it is not a popular one.

As a result, NPS is exploring the use of high occupancy vehicles such as busses, and reducing the amount of pollution produced by each vehicle. Biodiesel has been proposed as the fuel for these high capacity vehicles because it reduces harmful air emissions, has a less noxious smell than diesel, and is readily biodegradable in the event of a spill. In addition, 100 percent biodiesel is safer to handle, having a higher flash point than diesel and lower toxicity. Montana Department of Environmental Quality initiated this project, called "Truck-in-the-Park," to demonstrate the viability of biodiesel in tourism related industries such as those found at YNP.

1.1 Project Overview

The Truck-in-the-Park project is a jointly funded research project which demonstrates the benefits of the use of biodiesel in tourism related industries. Participants include

- Montana Department of Environmental Quality;
- National Park Service;

- United States Department of Energy, Regional Biomass Energy Program;
- Wyoming Department of Commerce Energy Office
- Dodge Truck, a division of the Chrysler Corporation;
- Koch Agri-Services of Great Falls, Montana;
- Cummins Engine Co. and Cummins Intermountain Distributors;
- Western States Caterpillar;
- J.R. Simplot Company;
- University of California, Davis;
- and the University of Idaho.

NPS operated the truck in Yellowstone for 149,408 km (92,838 miles) on 100 percent canola and rapeseed ethyl ester (CEE and REE) Biodiesel fuel produced by the University of Idaho. The majority of the on-road fuel used was from off-grade canola oil. This oil was obtained from Koch Industries, Great Falls, Montana, and processed by the Biological and Agricultural Engineering Department at the University of Idaho. The fuel used initially and during the emissions tests was rapeseed ethyl ester. The main focus of the project is to demonstrate to NPS, tourism operations, and potential fuel producers, the reliability, benefits, and costs of using biodiesel in their vehicle operations in Yellowstone.

1.2 Test Vehicle

The vehicle used for this test was a 1995 Dodge 2500 4-wheel-drive pickup truck equipped with a Cummins B 5.9L turbo-charged and direct-injected diesel engine. The truck was donated for use in the project by the Chrysler Corporation. The truck was operated for 149,408 km (92,838 miles) by NPS personnel stationed at the Mammoth Hot Springs

Maintenance Center in Yellowstone. The maintenance personnel at Yellowstone provided for general maintenance, fueling, and the truck's daily operations and reports.

Since fuel was only available at two locations (the Yellowstone National Park maintenance garage at Mammoth Hot Springs and the University of Idaho in Moscow, Idaho), an in-bed slip tank of 100 gallon capacity, later increased to 300 gallons, was added by the NPS. The vehicle was ordered with the standard winterization package for federal fleets that included low temperature engine coolant, engine block heater, and battery heaters. In addition, an external (electric, magnetic) fuel tank heater, and a heating loop to the slip tank using engine coolant were added by NPS.

The truck was parked in a garage at night or plugged into an outlet when temperatures dropped below –6.7 C (20 F) (Haines and Evanoff, 1998).

The other vehicle modifications included the addition of three-way valves in the fuel lines for switching fuels during emissions testing, special lettering describing the biodiesel fuel and the project sponsors, a canopy, and running boards with splash guards.

1.3 Fuel Production and Quality Assurance

The fuel used for most of the truck's operation was Canola Ethyl Ester (CEE) which was produced from off-spec canola supplied by Koch Agri-Services of Great Falls, Montana. Some initial fuel and all fuel for the emissions tests was made from rapeseed oil. The CEE was esterified with fuel-grade ethanol provided by the J.R. Simplot Company of Caldwell, Idaho, with potassium hydroxide (KOH) used as a catalyst. The fuel was delivered in seven 3000-3800 liter (800-900 gallon) lots to Mammoth Hot Springs where it was stored in a 37,850 liter (10,000 gallon) tank provided by NPS. The University of Idaho performed detail

fuel analysis on each lot of fuel delivered. Details about the fuel quality, quantity, delivery, and production can be found in Chapter 3, Fuel Production and Quality Assurance.

1.4 Engine Performance Testing

The truck was performance tested a total of four times using a SuperFlow SF-601 Chassis Dynamometer at Western States Caterpillar of Spokane, Washington, and one time at Tractor and Equipment (T & E) of Billings, Montana, with similar equipment. The condition of the cylinder bore, injector coking, injector pressures, and engine compression were also measured at the dynamometer test interval. Results of the performance and engine tests are detailed in Chapter 4, Engine Performance Testing.

1.5 Engine Durability

Engine durability was qualitatively examined by looking at several parameters. An engine oil sample was taken at each oil change interval and sent to Chevron LubeWatch for analysis. At the end of the project, the engine was removed by Cummins Intermountain Distributor in Pocatello, Idaho, and disassembled for inspection. The engine was then transported to the University of Idaho for detailed measurements of the internal engine parts. The fuel injection pump was removed from the engine and sent to Bosch for detailed examination. Despite low mileage, these data collectively give a good indication of the fuel's impact on this engine's durability. The oil analysis, engine teardown analysis, internal engine component measurements, and fuel pump evaluation are presented in Chapter 5, Engine Durability.

1.6 Engine Emissions

The truck was emissions tested at the Los Angeles Metropolitan Transit Authority's (LAMTA) Emissions Testing Facility (ETF) using the EPA Driving Schedule for Heavy-Duty Vehicles. The vehicle was tested at 5,955 km (3,700 mi.) in 1995 and again at 139,466 km (86,660 mi.) in 1998. Fuels tested during each emissions test included 100 percent Rapeseed Ethyl Ester (REE), 100 percent Diesel control fuel, 20 percent REE/80 percent Diesel, 50 percent REE/50 percent Diesel. Emissions data collected included hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), carbon dioxide (CO_2), and particulate matter (PM). The vehicle was tested with and without the original equipment catalytic converter. Comparisons between the 1995 and 1998 tests as well as with and without the catalytic converter are made and statistically analyzed. The details of the emissions testing can be found in Chapter 6, Engine Emissions.

In summary, this is the final technical report for the Truck-in-the-Park project by the University of Idaho, Department of Biological and Agricultural Engineering. This report details the fuel production and quality control, engine performance and durability, and engine emissions tests performed on the Truck-in-the-Park test vehicle. It does not include results of the emissions toxicity tests which are to be reported separately by the University of California, Davis.

2 LITERATURE REVIEW

The literature summarized in the topics below are a brief survey of the typical works done in each field. For a more comprehensive review of current research in the area of biodiesel fuels, see Tyson, et al. (1997). Peterson and Reece (1996) give a detailed overview of chassis dynamometer and emissions tests with biodiesel fuels, and Zhang, et al.(1998) outline the current literature in the area of biodegradability. It is not the intention of the author to reproduce those reviews in this report.

2.1 The Diesel Engine

The modern compression ignition internal combustion engine was patented by Rudolf Diesel in 1892 and a working prototype was built in 1893. Originally, Diesel proposed the use of pulverized coal as a fuel source, (Stone, 1992). The use of coal as a diesel engine fuel was never fully realized, but he reportedly demonstrated his diesel engine at the 1900 World Exposition in Paris running on raw peanut oil. Thus, the vision of using vegetable oil fuels in diesel engines is not a new concept.

2.2 Early Work – Raw Vegetable Oils

When vegetable oils were first seriously considered as petroleum diesel replacements or extenders, raw vegetable oils used either neat or in blends were examined. Schlick, et al. (1986) report one such attempt at using raw soybean and sunflower oil in a 25 percent blend with petroleum diesel fuel. While the fuel performed satisfactorily, there were significant deposits on all combustion chamber parts at only 200 hours operation.

Many different kinds of raw vegetable oils have been used by various researchers. Akor, et al. (1983) used raw and esterified palm oil in diesel engines. They found that the high viscosity of the raw oils caused problems with fuel atomization and fuel flow. They also noted lower efficiencies with palm oil compared to petroleum diesel.

Wagner (1984) looked at engine deposits and durability of Wisconsin WD2-1000 1.0L direct injected engines fueled with blends of raw rapeseed oil and safflower oil. His tests were performed at the University of Idaho's long term engine testing facility running the Engine Manufacturer's Association (EMA) 200 hour test. Even at a blend level of 50 percent with diesel, he observed significant carbon deposits on all combustion chamber components, including heavy coking of the injector tips and ring sticking for the vegetable oil fueled engines. Based on his short term testing and teardown observations, he concluded that engine life would be drastically reduced for the engines fueled with the raw vegetable oil blends.

Van Der Walt and Hugo (1982) looked at direct injection diesel engines fueled with sunflower oil and ways to prevent deposits on injector tips. Like other researchers, they experienced extensive coking of the injector tip due to polymerization of the oil at high temperatures. Their research examined ways to reduce coking by various engine modifications such as cooling the injector tip, retracting the injector from the combustion chamber, and heat shielding. They were unsuccessful in reducing the amount of coking of the injector with an engine fueled with raw sunflower oil.

These experiences are typical of those running raw vegetable oils in compression ignition engines. In general, most researchers concluded that raw, unmodified vegetable oils are not suitable for direct use in diesel engines due to excessive engine deposits, injector

coking, poor fuel injector spray patterns, and flow problems due to the very high viscosity. However, the use of raw vegetable oil may be feasible in blends of 20 percent or less with pre-combustion chamber engines (Reece and Peterson, 1995).

2.3 Transesterified oils

After it was realized that raw oils were not suitable for use in unmodified diesel engines, the process of transesterification was examined to bring the raw oil's physical properties closer to those of 2-D diesel fuel. Transesterification is the process of displacing the glycerol from fats, usually with an alkaline catalyst in the presence of an alcohol such as ethanol or methanol. The resulting product of this process is called an ester (Swern, 1979). The generally accepted name for a vegetable oil ester used as a diesel fuel replacement is "biodiesel."

Biodiesel has some advantages over raw vegetable oils for use as a diesel fuel substitute. Biodiesel has a viscosity about a factor of ten less than raw oils which makes them about twice the viscosity of diesel fuel. Because they have a viscosity much closer to diesel fuel, biodiesel tends to behave more like diesel fuel when sprayed from a diesel injector nozzle. Biodiesel still has some mild operational issues which can cause undesirable operation in some engines or environments. Pour points and cloud points are much higher than diesel fuels which can cause filter plugging and operational difficulties in colder climates. Biodiesel also tends to have lower gross heating values, about 11 percent less than diesel, but a greater density than diesel, which tends to counteract the effects of the lower energy content. On the positive side, biodiesel has a higher cetane rating than diesel. It also has a much higher flash point making it safer to handle, (Peterson, 1986).

2.4 Engine Durability and Long Term Testing

Engine manufacturers are naturally concerned with how vegetable oil based fuels will affect their engine's operational lifetime and emissions. Shäfer (1994) of Mercedes-Benz reported problems with certain engine components and fluids subjected to long term exposure or use of vegetable oil methyl esters. These problems included engine oil breakdown, oil dilution, and rubber degradation. Problems such as inlet valve and injector nozzle coking appeared when esters of insufficient quality were used. Goyal (1994) echoed these concerns as they relate to John Deere engines and warranty coverage when using biodiesel fuels.

As a result of these concerns, most diesel engine manufacturers either will not warranty engines fueled with biodiesel or specify very strict parameters on the fuel properties to ensure biodiesel fuel of the highest quality is used. A recent joint statement from the Diesel Fuel Injection Equipment (FIE) manufacturers details their concern. They cite the need for quality biodiesel fuel and the importance of a uniform standard and testing protocol. They concluded by issuing a position statement that the use of biodiesel in blends in excess of 5 percent (vol) will result in the nullification of the warranty on their fuel system components (FIE, 1998).

2.4.1 EMA tests

The Engine Manufacturers Association (EMA) has devised a 200-hour testing protocol for screening diesel engines fueled with alternative fuels. The test is designed to show engine durability problems in a relatively short period of time and allows assessment of the potential impacts of these fuels on durability (EMA, 1982).

Perkins, et al. (1991) ran a 1,000-hour test on three Yanmar engines fueled in turn with 100 percent RME, 50 percent RME blended with diesel, and 100 percent diesel control fuel. The 1,000-hour test was composed of five back-to-back 200-hour EMA tests. They found that the RME performed similar to diesel with respect to engine wear and long term performance. However, it was noted that a slight decrease in engine oil viscosity was experienced with the ester fuel.

Peterson, et al. (1997) ran a similar 1,000-hour test with various blends of Hydrogenated Soybean Ethyl Ester (HySEE) biodiesel. The blends tested were 100 percent HySEE, 50 percent, and 25 percent HySEE with 2-D diesel. They performed engine oil analysis for wear metals at each oil change interval and concluded that the indicated wear of the 100 percent HySEE fueled engine was equivalent or better than that of the 25 percent and the 50 percent HySEE fueled engines. In addition, it was noted that the internal components of the 100 percent HySEE fueled engine appeared cleaner and brighter than the 25 percent or 50 percent fueled engines.

2.4.2 On-Road Tests

Many researchers have tested biodiesel fuels in on-road vehicles to prove the fuel's viability in the real-world. Some of these vehicles were fueled with 100 percent neat biodiesel, some with blends. Typical problems encountered were rusting of mild steel components in the fuel system and hardening of rubber engine seals and hoses exposed to the fuel. Two such demonstration projects are summarized below.

Schumacher, et al. (1995) reported two Dodge (one 1991 and one 1992) pickup trucks fueled with 100 percent soybean methyl ester run for about 80,500 km (~50,000 miles) each. The trucks were equipped with the 5.9 liter Cummins B series engine. Engine coking did not

appear abnormal when inspected with an engine borescope. Engine oil analysis of the biodiesel fueled trucks showed lower engine wear compared to diesel as measured by three key contaminants, Fe (iron), Pb (lead), and Si (silicon). Both trucks produced slightly less power, lower CO, HC, PM and smoke, but higher NOx compared to diesel. OEM rubber fuel lines were rapidly deteriorated by the 100 percent soybean methyl ester fuel.

Peterson, et al. (1997) reported on a 1992 Dodge pickup with a 5.9L Cummins B series engine running 28 percent Rapeseed Methyl Ester (RME) with 72 percent Diesel for 161,000 km (100,000 miles). They looked at chassis dynamometer tests, engine oil analyses, injector coking, and injector valve opening pressures at regular intervals. Oil analysis reports indicated that no unusual deterioration of the engine took place. The engine was removed from the vehicle, disassembled, and examined by the engine manufacturer after 163,800 km (101,785 miles). The condition of the engine was characterized as good or better than would be expected with diesel. Engine parts were clean and showed little wear. Notable exceptions were hardening of the crankshaft seal, which wore a slight depression in the crankshaft, and rusting of the fuel filter attaching stud. Operational difficulties included rusting of the vehicle's mild steel fuel tank which contributed to fuel filter plugging.

2.5 Engine Emissions

After biodiesel's suitability and reliability in unmodified diesel engines was established, concern was focused on emission characteristics of biodiesel fuel. The only biofuel emissions currently regulated by EPA are hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx), oxides of sulfur (SOx) and particulate matter (PM) which are the pollutants commonly considered in the biodiesel literature. However, unregulated

mutagenic or toxic compounds and greenhouse gas emissions have become of increasing concern to researchers in anticipation of regulations related to these compounds in 2001.

2.5.1 Hydrocarbons and Carbon Monoxide

HC emissions are mostly the result of flame quenching in an internal combustion engine. There is a narrow quench zone near the cooled cylinder walls that makes the flame go out and the HCs are not burned. CO is partially combusted fuel. Because of this, HC and CO are typically very high on cold start due to colder engine parts quenching the flame and preventing complete combustion. (Stone, 1992). Biodiesel will produce less HC and CO than 2-D diesel fuel in the same engine, under the same conditions, (Peterson and Reece, 1996).

2.5.2 Oxides of Nitrogen

NOx (oxides of nitrogen) collectively refers to both NO and NO_2. NO is a colorless and odorless gas which gradually turns into NO_2 in air. Pure NO_2 is a poisonous, reddish-brown gas with a strong odor. NO_2 can cause mucous membrane irritation if exposed in high enough concentrations, (Bauer, 1996).

NOx formation is a very complex and can be described by the Zeldovich Mechanism, equation 2-1 below.

$$O_2 \Leftrightarrow 2O$$
$$O + N_2 \Leftrightarrow NO + N \qquad \text{(eq. 2-1)}$$
$$N + O_2 \Leftrightarrow NO + O$$

NOx formation generally increases with increases in flame temperatures and slower flame speed. NOx emissions also increase with reduced engine speed. While desirable for

high efficiency operation of a diesel engine, high temperatures and pressures are prime conditions for the formation of NO_x gasses, (Stone, 1992).

The NOx emissions behavior of biodiesel in unmodified diesel engines varies in the literature. Several reports show NOx is increased with biodiesel. However, chassis dynamometer tests with the Cummins B 5.9 Liter engine found a reduction in NOx with a corresponding increase in PM, (Peterson and Reece, 1996).

The variability in NOx response for biodiesel may be due to individual variables in the engines. Sharp (1996) said that there is "a strong link between increasing cetane numbers and reducing NOx emissions, but the response varies from engine to engine."

2.5.3 Particulate Matter and Smoke

Particulate emissions from diesel engines typically are much higher than from spark ignition engines. Particulate matter consists largely of carbon soot particles, hydrocarbons partially absorbed by the soot, and sulphates in the form of aerosols. Soot particles are chains of carbon particles that have a large surface area where hydrocarbons can be deposited. These deposited compounds are mostly strong-smelling aldehydes. It is widely believed that soot particles are especially harmful to human health because of these aromatic compounds in the soot and their small size. They are only a few ten thousandths of a millimeter and can enter the lungs very easily, (Adler, 1994).

Most researchers report reduced amounts of visible smoke and slightly less PM with biodiesel compared to diesel (Peterson and Reece, 1996). However, a detailed look at the transient emissions from a Cummins B 5.9L diesel engine by Sharp (1996) suggests that the observed reductions in smoke and particulate matter when fueled with biodiesel were due to carbon soot reduction while the mass of volatile organic fraction (VOF) increased. Sharp

also observed, "The net decrease in total particulate using biodiesel fuels would have been larger but the increase in VOF partially offset the reduction in soot. An exhaust catalyst typically reduces the VOF of the particulates." This resulted in greater PM reduction efficiency from the catalyst when fueled with biodiesel due to the catalyst's greater effectiveness in reducing the VOF portion of the biodiesel particulate emissions.

2.5.4 Testing Protocols

The protocols available to perform emissions tests on internal combustion engines are separated into two basic classes, PTO engine tests and chassis driving tests. PTO tests load the engine at the flywheel and loads are applied as a percentage of their rated speed and power. This type of testing is usually used for truck engines which can be installed in any number of custom built chassis where individual tests would simply be too costly. Federal Test Procedures (FTP) outlined in the Code of Federal Regulations (CFR) Title 40, Part 86, Subpart N dictate specific requirements for transient testing of emissions from heavy duty diesel engines. Chassis driving tests require the engine to be installed in a vehicle chassis and loading is applied to the wheels of the vehicle. This kind of testing can be used to more closely simulate true road conditions in a vehicle such as stop-and-go urban traffic. FTP test cycles used for driving tests are outlined in the CFR Title 40, Part 86, Appendix I.

2.6 Environmental and Health Effects of Biodiesel

In addition to regulated emissions, other concerns when considering any new fuel for internal combustion engines include air toxics, their mutagenic properties, and general health effects.

2.6.1 Air Toxics

Kado, et al. (1996) reported on bioassay testing of the Truck-in-the-Park. The emissions from REE biodiesel used neat and in blends compared with diesel control fuel were examined. Of interest were polycyclic aromatic hydrocarbons (PAH). Many of these compounds, typically found in diesel exhaust, are known or suspected carcinogens. This team of researchers found that emissions of polycyclic aromatic hydrocarbons (PAHs) were generally lower for REE and blends of REE than for conventional diesel. Also, many toxic species found in diesel exhaust were absent from the biodiesel exhaust samples. The exception was the PAH called benzo(a)pyrene which was slightly higher for 100 percent REE and 50 percent REE than for 100 percent diesel. Benzo(a)pyrene is commonly found in combustion products.

In 1998, Kado and his colleagues reported bioassay testing of 50 percent hydrogenated soybean ethyl ester (HySEE) fuels. The study looked at the particulates and semi-volatile compounds present in the exhaust of 100 percent HySEE, 50 percent HySEE blended with diesel, and 100 percent diesel fuel. The mutagenicity was rated in units of revertants per bhp-hr. The 100 percent HySEE mutagenicity emission rates were approximately 6 times lower than the diesel emission rates using an Ames test with metabolic enzymes added. The mutagenicity emission rates for the 50 percent HySEE blend were higher than the 100 percent HySEE emission rates, but lower than the 100 percent diesel emission rates.

2.6.2 Human Exposure Risks and Health Effects

Some concern was raised over the toxicity to humans who have ingested or who have been dermally exposed to biodiesel. Reece and Peterson (1996) looked at acute oral and

dermal toxicity and acute aquatic toxicity of rapeseed methyl ester (RME) and rapeseed ethyl ester (REE) biodiesel fuels and their blends with diesel. In general, they report that the occurrence of negative clinical observations increased as the ratio of diesel fuel in the blend being tested increased. 100 percent RME was the least severe in the acute oral toxicity study and the 100 percent REE was the least severe in the acute dermal toxicity study. In the aquatic toxicity tests, biodiesel was found to be less toxic than the reference toxicant (sodium chloride). Diesel fuel was 2.6 times more toxic than sodium chloride.

2.6.3 Greenhouse Gas Emissions and Ecological Effects

On December 10, 1997, 160 industrialized nations around the world signed a historic agreement in Kyoto, Japan, to reduce the future amount of carbon dioxide emissions and other so called "greenhouse" gasses to levels below those in 1990. It is widely believed by scientists that increased CO_2 in the atmosphere can cause global warming by restricting the reflection of infrared radiation back into space. Combustion of fossil fuels, which are composed of ancient carbon, increases the accumulation of carbon in the atmosphere, eventually leading to global warming. Peterson and Hustrulid (1998) conducted a carbon cycle study of rapeseed oil biodiesel fuels as compared to petroleum diesel. The authors suggest that any substitution of biodiesel for petroleum diesel will ultimately slow the accumulation of atmospheric carbon. The basis for this suggestion is that the carbon released from combustion of the biomass fuel has recently been extracted from the atmosphere by the oil producing plant, rather than releasing ancient carbon from petroleum.

Gibbs (1998) recently reported on the need for carbon-reduction technologies to offset carbon emissions from petroleum fuel use. The Kyoto Protocol requires reduction of CO_2 emissions from current levels to an amount 8 percent over 1990 levels for participating

industrialized nations, but the outlook seems grim given current trends. Gibbs predicted that the doubling time of vehicles worldwide would be reduced from 26 years to 6-10 years due to the emergence of active consumer economies in nations such as China, India, Mexico and the former USSR. This has the potential of increasing the atmospheric carbon levels by nearly 1 gigaton every 15-20 years. Biomass fuels offer considerable promise for reducing or stopping additional carbon release in the atmosphere by recycling atmospheric CO_2. Biodiesel has the potential to reduce atmospheric carbon levels released in combustion by over 11,000 tons per million gallons of REE biodiesel used (calculated using data from Peterson and Hustrulid, 1998)

Franke and Reinhardt (1998) looked at the environmental impacts of biodiesel fuels specifically. They performed a life cycle analysis of biodiesel fuel use and interpreted the environmental impacts based on CO_2 balances as well as other relevant parameters such as NO_x, SO_2, N_2O, PAH, dioxins, and furans. They concluded that RME has or can have an "overall" ecological advantage as compared to diesel fuel.

2.6.4 Biodegradability

Zhang, et al. (1998) examined the biodegradability of biodiesel in the aquatic environment using a CO_2 evolution method. They concluded that biodiesel fuels are readily biodegradable when introduced in neat form and also appeared to co-metabolize petroleum diesel fuels in blends. Diesel degradation rates when in a blend were increased to three times that of diesel alone due to co-metabolism.

2.7 Computer Combustion Models

In general, computer simulations of vegetable oil fuels combustion have not been explored extensively, but in the author's opinion have great potential for insight into the combustion and emissions differences between biodiesel and diesel. The lack of research is mainly due to the enormous computing resources required to run a detailed combustion analysis with the combustion modeling tools available. There is, however, at least one landmark paper in this area. In 1990, Vander Griend, et al. ran a KIVA combustion simulation of raw oils and methyl esters of winter rapeseed at Los Alamos National Laboratory. The KIVA model attempts to predict cylinder pressures over a complete engine cycle given parameters such as combustion chamber dimensions, injector spray geometries, and specific fuel properties. This research serves as a basis for validation of such models used with vegetable oil esters and shows the potential value of tools such as KIVA in the development of alternative fuels for CI engines.

2.8 Economic Aspects of Biodiesel

One of the main limitations of biodiesel as a viable alternative fuel is the cost. With the current price of diesel fuel at around one dollar per gallon (including state and federal taxes), the biodiesel industry has an uphill battle. Raw vegetable oil used to produce biodiesel typically costs well above twice that amount. Using waste or used vegetable oils is one solution to decrease the cost, but even used oil is more expensive than diesel fuel. Noordam and Withers (1996) conducted an economic feasibility study examining biodiesel production in the Inland Northwest. Considering mainly canola and rapeseed crops, they calculated the cost of producing Canola Ethyl Ester biodiesel. This fuel ranged from $1.69/gallon when harvested seed costs were $0.09/lb to $2.91/gallon when harvested seed costs were $0.15/lb.

The price of seed for crushing was the most influential factor in the estimated price. An increase of $0.01/lb of seed would cause an increase of $0.20/gallon of biodiesel. In their study, cost breakdown was 70 percent in seed costs (seed, transport, and storage), 5.5 percent for oil extraction, and 24.5 percent for transesterification of the oil based on $0.13/lb of seed.

Peterson, et al. (1995) looked at the potential of agriculturally produced fuels. They estimated that if all the idle agricultural land in the U.S. (approx. 17 percent) were placed into production of vegetable oils, nearly 27 percent of transportation fuel in the U.S. could be replaced by biodiesel. This equates to nearly 2.5 times that used in production agriculture. The major hurdle in implementing this kind of production is the enormous infrastructure cost.

3 FUEL PRODUCTION AND QUALITY ASSURANCE

The biodiesel truck was operated mainly on 100 percent Canola Ethyl Ester (CEE). The base canola oil for this fuel was supplied by Koch Agri-Services of Great Falls, Montana. It was an off-spec oil deemed unsuitable for human consumption. The esters were produced with ethanol from waste potatoes provided by the J.R. Simplot Company of Caldwell, Idaho.

3.1 Objective

The objective of this part of the project was to produce a quality fuel and deliver it to the Park Service for use in the Truck-in-the-Park pilot demonstration vehicle.

3.2 Materials and Methods

Fuel production and delivery was the responsibility of the University of Idaho, Department of Biological and Agricultural Engineering. Personnel from the University of Idaho produced the fuel and delivered it to the Park Service throughout the duration of the project. The following sections summarize the fuel production, equipment, storage, and delivery of the fuel to the Park Service.

3.2.1 Overview of the Fuel Production Process

The CEE fuel was produced in a 950 liter (250 gallon), stainless steel batch type reactor. The ethyl ester process utilizes 70 percent stoichiometric excess ethanol (anhydrous), or a molar ratio of 5.1:1 (ethanol:oil). Based on the amount of input oil by weight, 1.3 percent of potassium hydroxide (KOH) is used as a catalyst.

The oil is placed in the 950 liter (250 gallon) stainless steel reactor while the catalyst is dissolved into the alcohol by vigorous stirring in a separate, smaller reactor. The

catalyst/alcohol mixture is then transferred to the 950 liter (250 gallon) reactor and stirred for two hours.

The esterification reaction yields two liquid phases: ester and crude glycerol. Crude glycerol is a heavy liquid layer that collects at the bottom of the reactor after settling for several hours. Initial phase separation can be observed in as little as 10 minutes and is usually complete within two hours of settling, but can take as long as 20 hours.

After settling is complete, water is added at the rate of 5.5 percent by volume of oil and then stirred for 5 minutes. The glycerol is allowed to settle again. At this point, the glycerol layer contains crude glycerol, water, excess alcohol, and the catalyst. After the final settling, the glycerol layer is drained and the ester layer remains in the reactor.

Washing the ester is a two step process which is carried out with extreme care. A water wash solution at the rate of 28 percent by volume of oil and 1 gram of tannic acid per liter of water is added to the ester and gently agitated. Air is carefully introduced into the aqueous layer while gently stirring. This process is continued until the ester layer becomes clear. After settling, the aqueous solution is drained and water alone is added at 28 percent by volume of oil for the final washing, (Peterson, et al., 1995).

3.2.2 Equipment

The ester is produced in a 950 liter (250 gallon) stainless steel reactor. The reactor is a custom built unit designed by the University of Idaho. The reactor is equipped with an electric, explosion-proof stirring motor and a hydraulically operated stirring motor. The volatile alcohol can produce explosive mixtures in the air so all electric equipment must be rated as explosion proof. The electric stirring motor is used for stirring the alcohol catalyst mixture as well as initial stirring of the oil and alcohol/catalyst mixture. The hydraulic

stirring motor is used during the secondary stirring procedures where a more gentle stirring is needed. The hydraulic stirring motor is ideal for secondary stirring because its speed is infinitely adjustable by means of a hydraulic valve. The hydraulic stirring motor is driven by an electric powered hydraulic pump which is remotely located outside the building for safety reasons. Various electric pumps are used to transfer the alcohol/catalyst mixture to the reactor and pump the finished fuel from the reactor to various storage vessels.

3.2.3 Fuel Storage

The finished biodiesel fuel is stored temporarily in 1040 liter (275 gallon) plastic bottled totes. These totes are a convenient storage medium because they have reusable steel support cages and replaceable plastic bottles. The totes are also easily transportable and are small enough to be handled with a forklift. The original valves on the bottles had to be replaced with Viton sealed valves due to incompatibilities between the natural rubber in the original valves and the ester fuel.

3.2.4 Delivery

The biodiesel fuel was delivered in seven lots of about 3000-3800 liters (800-1000 gallons) each. The fuel was transported in three 1040 liter (275 gallon) totes with additional fuel transported in 208 liter (55 gallon) barrels. The containers were put on a flat bed trailer and hauled to Mammoth Hot Springs either with a 1994 Dodge pickup running on 100 percent Rapeseed Ethyl Ester (REE) or a 1992 Ford running on a blend of 20 percent raw rapeseed oil and 80 percent diesel fuel. The fuel was pumped into a 37,850 liter (10,000 gallon) tank at Mammoth Hot Springs. Since this tank was unheated, some of the fuel was stored indoors in a smaller fuel vault at the Mammoth Hot Springs maintenance shop. Both

of these storage tanks were maintained by the Park Service. Detailed fuel delivery reports are included as Appendix A.

3.2.5 Quality Assurance

Each batch of fuel delivered to the Park Service was analyzed for quality and consistency. Two independent labs were used to test the fuel produced. Phoenix Chemical Labs of Chicago, Illinois, was contracted to determine some of the physical properties of the fuel. Specifically, this lab reported water & sediment, ramsbottom carbon, ash, sulfur, cetane rating, copper corrosion, Karl Fischer water, particulate matter, carbon percent, hydrogen percent, oxygen percent, iodine number, and nitrogen in parts per million. Diversified Laboratories of Chantilly, Virginia, was contracted to determine the total glycerol, free glycerine, mono-glycerides, di-glycerides, tri-glycerides, free fatty acids, and ethyl ester content of the fuel.

3.3 Results

A table summarizing the fuel specific properties for all delivered fuel is presented in Table 3-1. Copies of the original fuel properties reports from the two labs are included in Appendix B.

3.4 Conclusions

- The batch method of production was sufficient for small lots of fuel produced for this project.
- 275 gallon totes proved to be effective for transportation and temporary storage of fuel.
- Fuel should be kept heated to ensure ease of handling in cold environments.

- This project showed that normal cold-weather diesel modifications as described in section 1.2 were sufficient to enable use of biodiesel in cold-weather operations as found at Yellowstone National Park.

Table 3-1. Fuel specific properties of delivered fuel.

	Lot 1	Lot 2	Lot 3	Lot 4	Lot 5	Lot 6	Lot 7
Fuel Specific Properties	REE	REE	REE/CEE	CEE	CEE	CEE	CEE
Specific Gravity, 60/60	0.8755	0.8755	0.8788	0.8795	0.8798	0.880	0.880
Viscosity, cSt @ 40°C	6.123	6.115	5.15	4.86	4.88	4.76	NA*
Cloud Point, °C	0	0	0	-5	-6	-6	-6
Pour Point, °C	-12	-12	-12	-12	-12	-9	-9
Flash Point, °C	170	175	175	170	194	126	NA
Boiling Point, °F	440	510	570	656	479	568	512
Water and Sediment, % vol.	0.01	<0.005	<0.005	0.02	Nil	Nil	<0.005
Carbon Residue, % mass	0.062	0.050	0.069	0.070	0.054	0.05	0.00
Ash, % mass	0.011	0.003	0.002	0.002	0.002	0.003	0.000
Sulfur, wt%	0.022	0.019	<0.005	<0.005	<0.001	<0.005	<0.005
Cetane Number	59.5	58.4	56.9	55.3	55.2	59.8	53.9
Heat of Combustion, Gross, MJ/kg	40.72	40.6	40.31	40.22	40.02	45.05	NA
Copper Corrosion	1A	1A	1A	1A	1A	1A	1A
Karl Fischer Water, ppm	757	795	1090	1108	1095	NA	NA
Particulate Matter, mg/L							
Total	2.44	1.97	1	8.9	0.89	1.59	12.48
Non-Combustible	0.4	0.56	0.03	<0.01	0.28	0.51	3.36
Elemental Analysis							
Nitrogen, ppm	14	5	3.1	NA	14	78	NA
Carbon, %	77.15	78.16	77.31	77.10	77.07	80.74	78.08
Hydrogen, %	9.52	12.42	9.45	9.80	12.04	12.25	12.08
Oxygen, % (by difference)	13.3	9.42	13.24	13.1	10.89	7.01	9.84
Iodine Number	97.5	94.8	109	113.7	110.7	111.0	117.3
Ester Specific Properties							
Acid Value	0.13	0.106	0.13	0.183	0.154	0.165	0.1913
Free Glycerol, %wt	1.21	0.14	0.13	0.2	0.02	0.00	0
Total Glycerol, %wt	2.03	0.39	0.31	4.09	0.54	0.333	1.482
Free Fatty Acids, %wt	0	0.64	0.41	0.42	0.42	0.40	0.097
Monoglycerides, %wt	<0.50	0.22	<0.50	trace	2.97	1.035	1.024
Diglycerides, %wt	1.66	1.95	3.37	4.63	3.40	0.333	0.689
Triglycerides, %wt	1.33	0.46	1.79	2.7	2.21	0.193	1.097
Alcohol Content, % mass	<1%	<1%	<1%	<1%	<1%	<1%	<1%
Catalyst, microgram/gram	5	<1.4	<1.4	<1.4	<1.4	<1.4	<1.4
Fatty Acid Composition, %							
Palmitic (16:0)	2.67	2.4	3.2	3.5	3.5	3.5	3.5
Stearic (18:0)	1.9	2	4.6	6.4	6.4	6.4	6.4
Oleic (18:1)	12	11.7	43	54.2	54.2	54.2	54.2
Linoleic (18:2)	11	10.7	16.5	18.4	18.4	18.4	18.4
Linolenic (18:3)	8.11	8.1	9.3	9.4	3.5	3.5	9.5
Eicosenoic (20:1)	6.76	5.8	2.5	1.4	1.3	1.3	1.3
Behenic (22:0)	4.37	5.3	2.3	0	0	0	0
Erucic (22:1)	44.62	45.1	13.1	1.3	1.4	1.4	1.4

* NA = Not Available

4 ENGINE PERFORMANCE TESTING

Engine performance was determined through chassis dynamometer tests conducted by the University of Idaho. Additional parameters were examined at the dynamometer test intervals including condition of cylinder bore, injector coking, injector pressures, and engine compression. This chapter details engine performance testing on the chassis dynamometer while the following chapter examines the additional parameters with respect to engine durability.

4.1 Objectives

The objective of vehicle performance testing was to monitor engine performance to detect any emerging problems.

4.2 Materials and Methods

The test vehicle was performance tested at Western States Caterpillar in Spokane, Washington, or Tractor & Equipment in Billings, Montana, a total of five times. The vehicle was tested at 4,764 km (2,960 miles), 25,465 km (15,823 miles), 42,165 km (26,200 miles), 81,726 km (50,782 miles) and 142,186 km (88,350 miles). The facilities were equipped with a SuperFlow SF-601 chassis dynamometer and Caterpillar PAR software. The SF-601 chassis dynamometer is a water-brake dynamometer capable of applying a fixed load to the drive wheels. A lug curve was produced by programming 11 lug points into the computer. These lug points started at 1450 RPM and proceeded to 2950 RPM with 150 RPM intervals. Three replicates of the lug curve were made for both 2-D diesel and for biodiesel fuels.

4.3 Results and Discussion

Figure 4-1 compares the overall average of all the dynamometer tests for REE/CEE biodiesel and diesel. The values are a composite of all REE/CEE biodiesel and diesel runs for the five dynamometer test events. This figure shows that REE/CEE biodiesel has slightly less power than diesel which is expected due to the lower energy of the REE/CEE biodiesel per volume

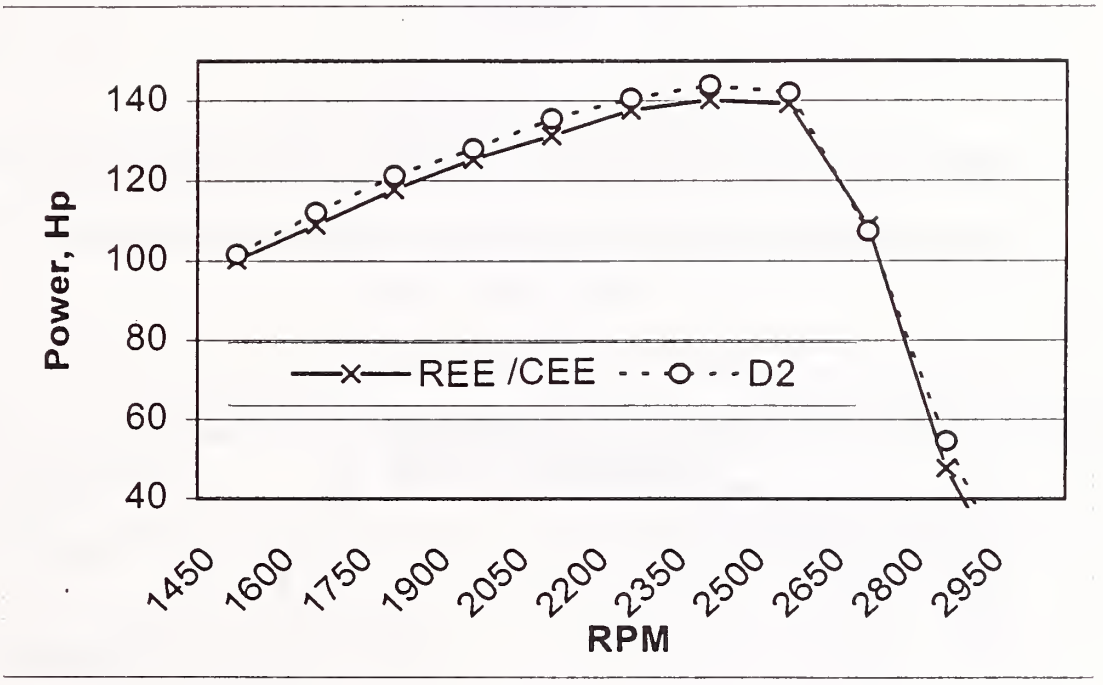

Figure 4-1. Overall Average of REE/CEE Biodiesel and Diesel runs.

The early dynamometer tests were done on REE and the later tests on CEE.

REE/CEE biodiesel averages for each dynamometer test are displayed in Figure 4-2. Each series represents the average of the three REE/CEE biodiesel replicates performed during that single dynamometer test event. Figure 4-3 shows similar data for the diesel tests.

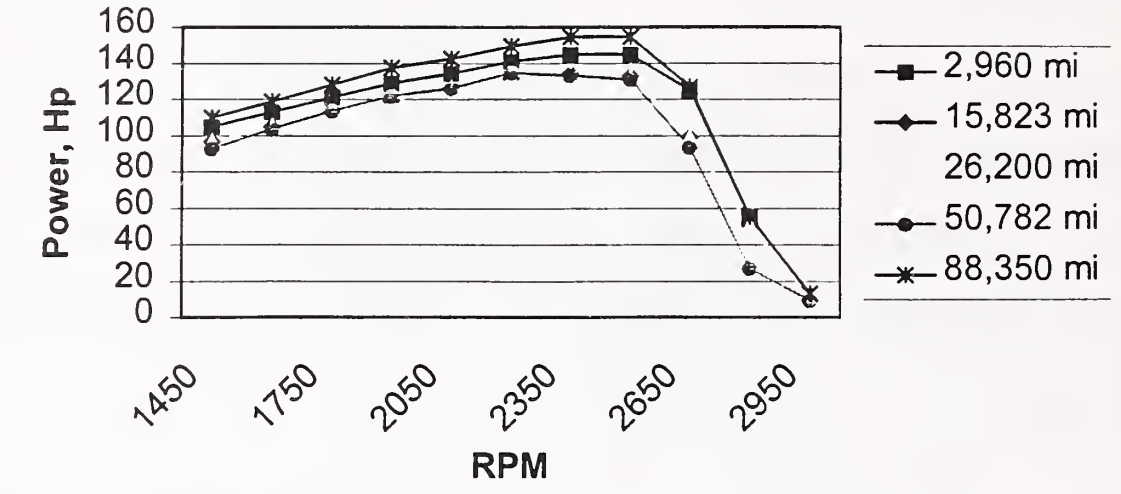

Figure 4-2. Average of REE/CEE Biodiesel runs at each testing interval.

The early dynamometer tests were done on REE and the later tests on CEE.

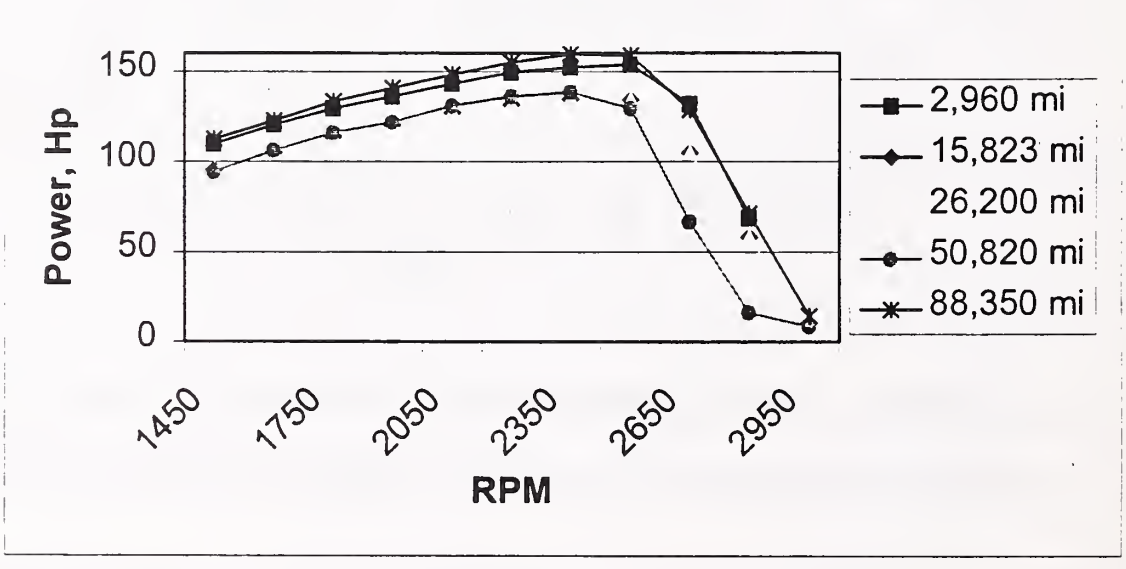

Figure 4-3. Average of the diesel runs at each testing interval.

The early dynamometer tests were done on REE and the later tests on CEE.

Figure 4-4 shows that the vehicle did not experience a sustained reduction in power over time. There was some variability in power over time, but this may be attributed to

variables such as different testing locations (Billings and Spokane), environmental effects such as high ambient temperature and different dynamometer software on the last test.

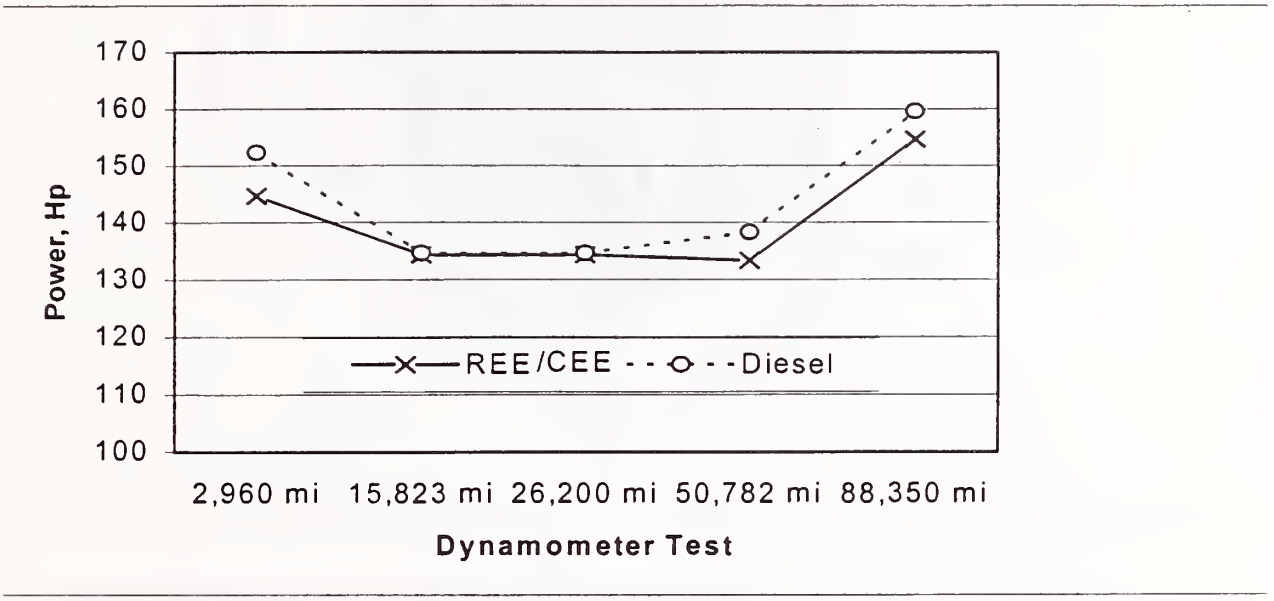

Figure 4-4. Comparison of average power at 2350 RPM over time for diesel and REE/CEE Biodiesel.

The early dynamometer tests were done on REE and the later tests on CEE.

4.3.1 Engine Cylinder Compression

Engine cylinder compression tests were performed on the engine at each engine performance test interval. Cylinder compression varied from 450 psi to 500 psi, but individual cylinders didn't vary by more than 7 percent of the average of all cylinders for that particular test. The results are given in Figure 4-5.

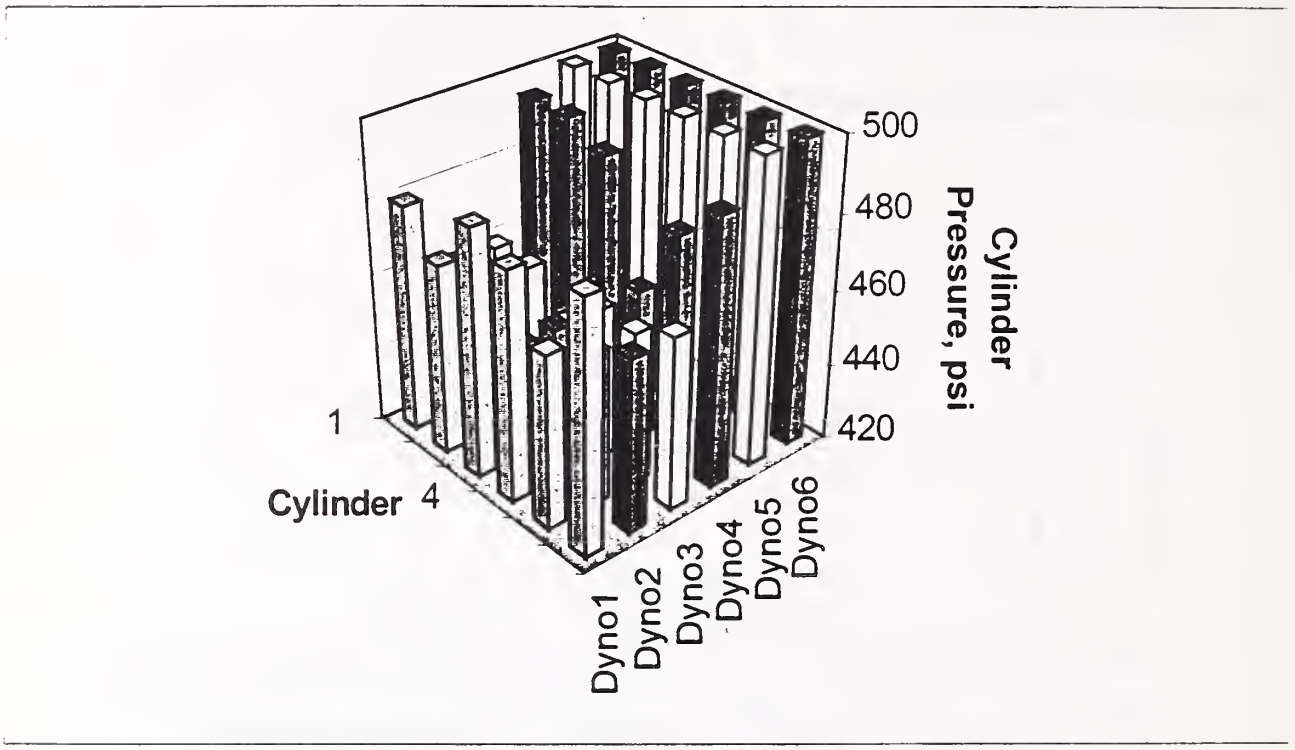

Figure 4-5. Cylinder compression at each dynamometer test interval.

4.3.2 Fuel Injector Valve Opening Pressure

Injector valve opening pressure tests were performed on the injectors at each engine performance test interval. Injector pressures varied from 3400 psi to 3950 psi, but each injector didn't vary by more than 6 percent of the average during that particular test. The results are given in Figure 4-6. Notice that valve opening pressures tended to decrease over time. This agrees with the injector evaluation performed at the engine teardown performed by Cummins Intermountain Distributor which reported lower than normal injector valve opening pressures. Bosch reported that valve opening pressures were low, but not abnormal for the mileage of the engine. Both of these reports are summarized in later sections of this chapter.

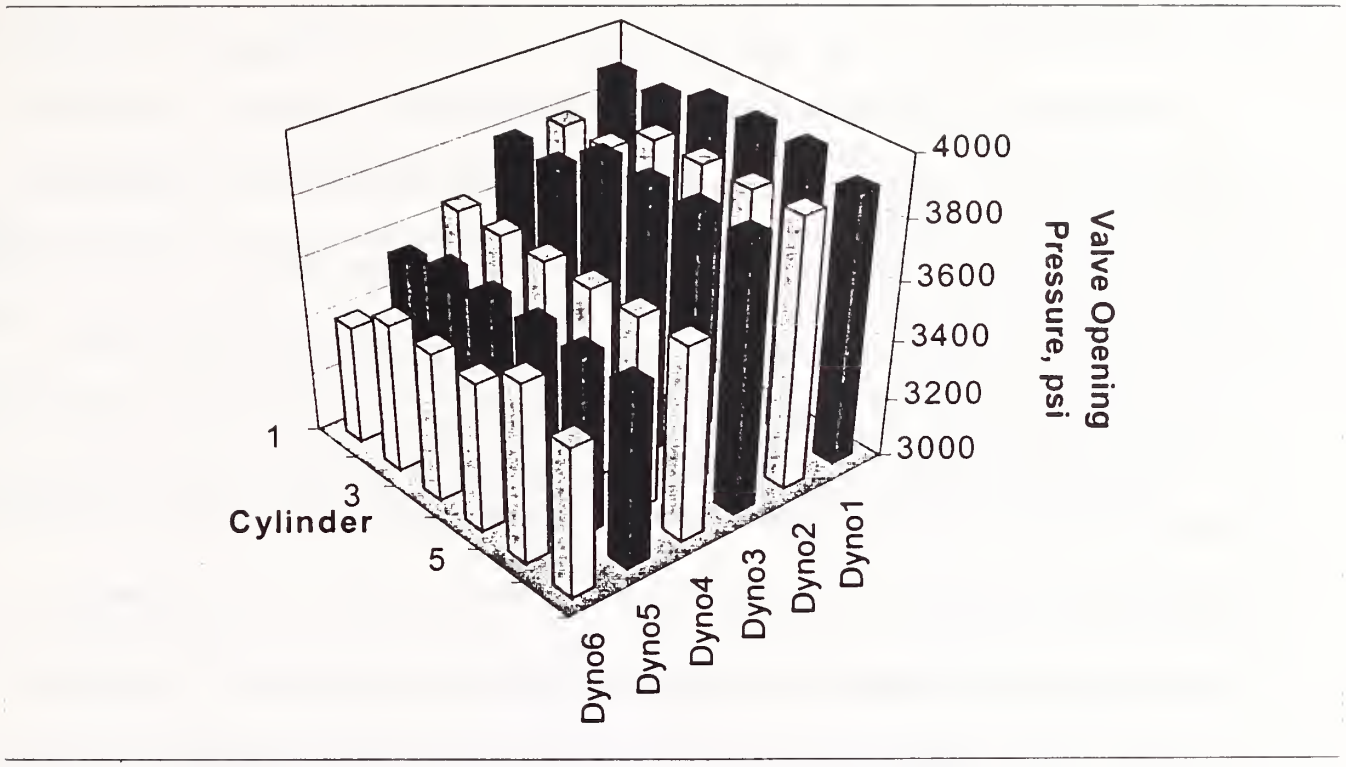

Figure 4-6. Injector valve opening pressure at each dynamometer testing interval.

4.3.3 Cylinder Borescope Inspections

A cylinder borescope was used to visually inspect the cylinder walls, tops of the pistons, and combustion chamber for excessive coking or premature wear. The borescope was inserted into the injector holes in the head while the injectors were removed for valve opening pressure tests. Inspections were performed at each dynamometer test interval. The borescope inspections did not show any evidence of excessive coking or premature wear of the engine.

4.3.4 Injector Coking

The fuel injectors were removed and examined for excessive coking or build-up after each dynamometer test. The build-up on injectors did not appear excessive between test runs and was comparable to that of diesel fuel in the same engine.

4.4 Conclusions

Performance of the engine varied, but the vehicle did not experience a sustained reduction in power over time. Vehicle testing also showed that REE/CEE biodiesel has slightly less power than diesel which is expected due to the lower energy of the REE/CEE biodiesel fuel per volume. Cylinder compression varied from 450 psi to 500 psi, but individual cylinders didn't vary by more than 7 percent of the average for all cylinders for that particular test. The valve opening pressures tended to decrease over time. Cummins Intermountain Distributor also reported lower than normal injector valve opening pressures. Bosch reported that valve opening pressures were low, but not abnormal for the mileage of the engine. The borescope inspections did not show any evidence of excessive coking or premature wear of the engine.

5 ENGINE TEARDOWN AND DURABILITY ANALYSIS

Overall engine durability was estimated by considering engine oil analysis data, engine teardown inspection, engine component measurements, and an evaluation of the fuel injection pump by the manufacturer. Engine durability was difficult to determine directly in this test since the engine was only in service for 149,408 km (92,838 miles), considerably shorter than its expected service life. This chapter summarizes these observations and measurements.

5.1 Objectives

The objective of the teardown and durability analysis is to determine if any abnormal or excessive wear occurred with the engine due to the use of biodiesel fuel.

5.2 Materials and Methods

The truck was moderately to heavily loaded during its operation at the park. Most of this load was the 1,135 liter (300 gallon) auxiliary fuel tank that was installed by the Park Service to extend the truck's useful range. When full, the truck was nearly at its recommended load capacity. On occasion, the truck was used to haul livestock trailers for the Park Service and was used off-road. The Park Service maintained a detailed fueling and driving log which cataloged the type of driving the truck experienced. This log is included as Appendix C.

5.2.1 Engine Oil Analysis

Oil was analyzed at every oil change using Chevron Lube Watch analysis services of Spokane, Washington. A small sample was taken during the oil drain procedure and submitted to the lab for analysis. The LubeWatch service reports a number of wear metals, oil contaminants, and other parameters such as viscosity and total base number.

5.2.2 Teardown

The engine was removed and disassembled for inspection by Cummins Intermountain distributor of Pocatello, Idaho, on July 7, 1998. Representatives from Yellowstone National Park, Montana Department of Environmental Quality, Technology and Engineering Management, and the University of Idaho participated in the detailed inspection. Notes were taken on a check-sheet supplied by the University of Idaho.

5.2.3 Engine Measurements

After the engine was disassembled by Cummins Intermountain Distributor, the engine components were transported to the University of Idaho's research lab for additional engine measurements. Engine measurements were taken by University of Idaho personnel following the procedure outlined in the Dodge Truck service manual. Engine measurements were compared to the published values to determine if any critical dimension was out of specification.

5.2.4 Fuel Pump Inspection

Particular attention was paid to the effects of the fuel on the high pressure fuel pump. The pump used on this engine was a Bosch in-line mechanical injection pump. After removal from the engine and preliminary inspection at Cummins Intermountain Distributor, it was sent to Bosch for a more detailed analysis. Bosch provided a complete evaluation report on the pump which is summarized in the results section.

5.3 Results and Discussion

Results of the oil analysis, engine teardown, engine measurements, and fuel injection pump inspection are given below.

5.3.1 Engine Oil Analysis

A summary of the oil analysis wear metals of interest are shown in Figure 5-1. Initial high levels of contaminants such as iron (Fe), copper (Cu), silicon (Si) are shown in this figure and are due to the normal initial break-in of the engine.

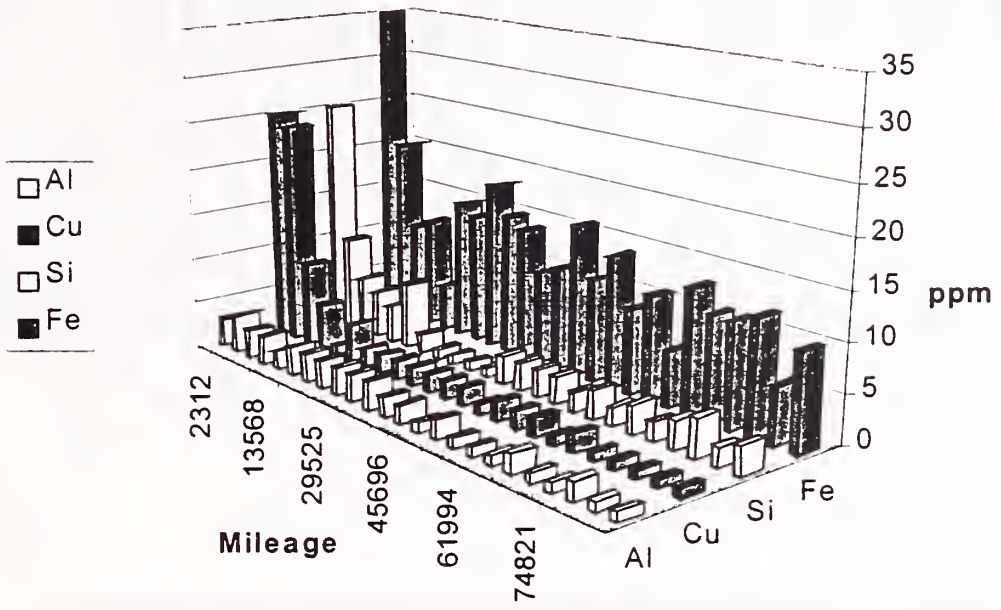

Figure 5-1. Wear metals in the engine oil at each oil change interval.

In addition to wear metals, LubeWatch reports engine oil viscosity as is presented in Figure 5-2. Four tests showed significantly lower viscosity than the other tests. This was due to fuel dilution coming from the injector pump during longer periods of idling in cold weather. Oil change intervals were shortened from about 6400 km (4000 miles) to about 4800 km (3000 miles) to help alleviate this condition. It is also worth noting that during the engine teardown, one of the o-ring seals inside the fuel pump was found to be damaged. This could have been the

source of the higher than normal fuel dilution but did not appear to be the fault of the biodiesel fuel. Copies of the LubeWatch reports are included as Appendix D.

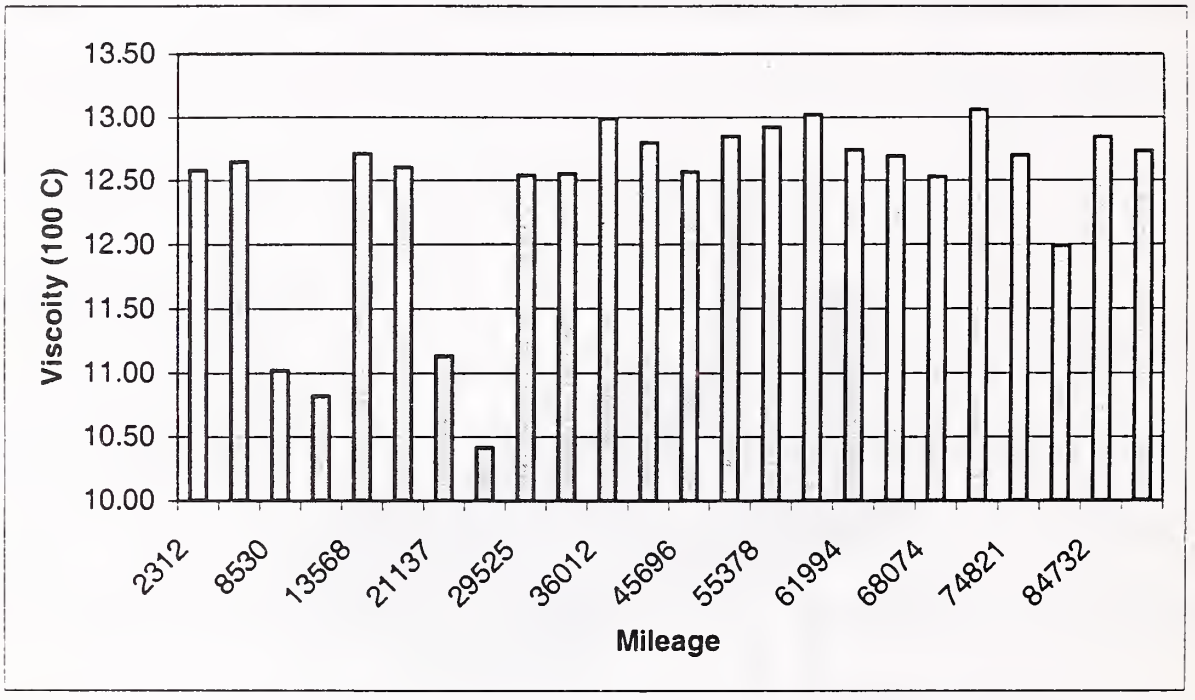

Figure 5-2. Viscosity of the engine oil at each oil change interval.

F-soot is shown in Figure 5-3. In general, the truck had very low levels F-soot in the engine oil. F-soot is the measure of carbon residue in the engine oil from combustion. Lower levels of soot in the engine oil, compared to an engine operating on 2-D diesel fuel, were also visually evident during the engine teardown. Most components appeared cleaner than a comparable diesel engine due to the lower amount of soot in the engine oil.

Total base number (TBN) is shown in Figure 5-4. Low TBN can cause unnecessary corrosion of the upper piston, piston rings, and top end bearing. Additionally, low TBN is indicative of reduced oil detergency. In general, the TBN remained within safe levels due to the relatively frequent oil changes.

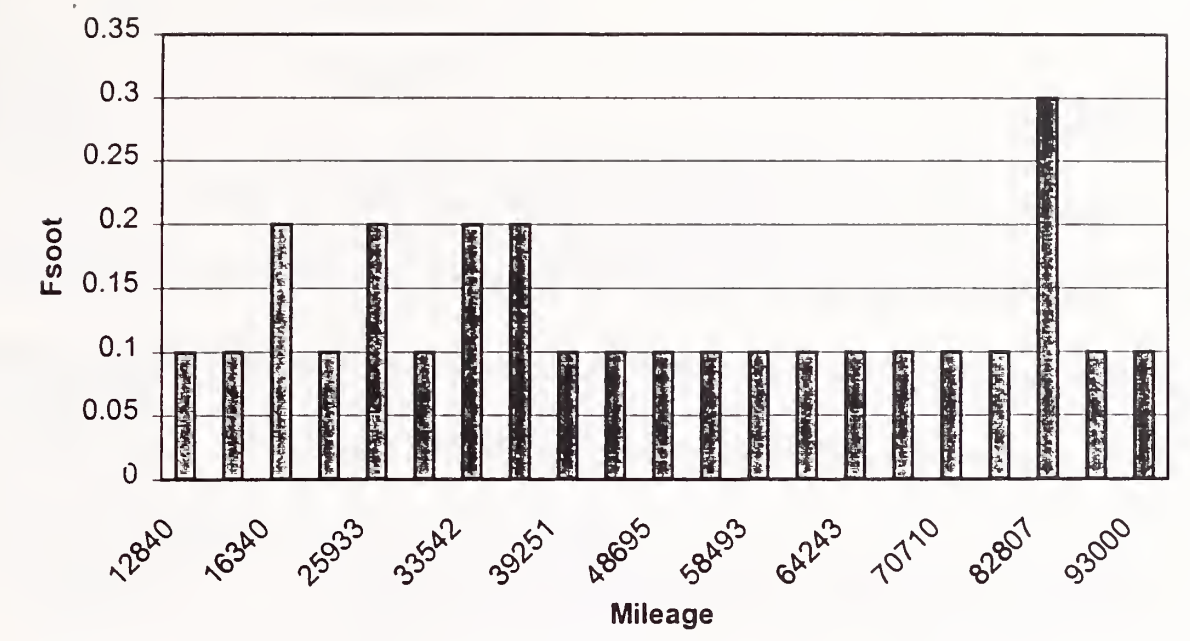

Figure 5-3. F-Soot number of the engine oil at each oil change interval.

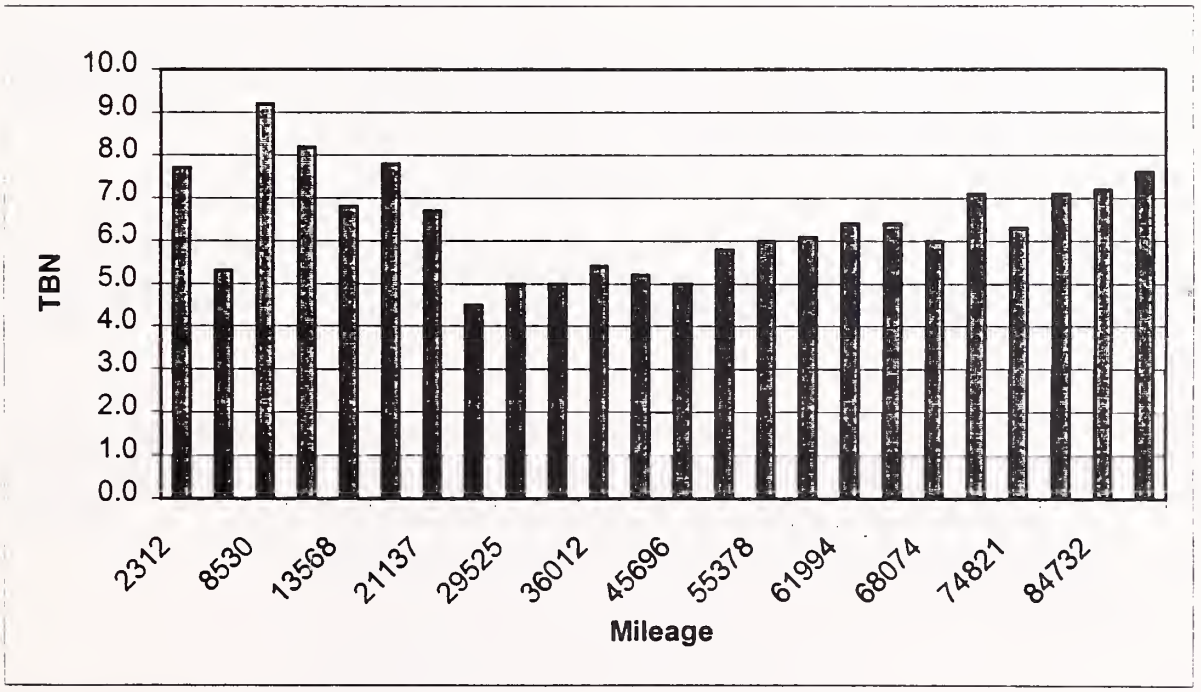

Figure 5-4. Total base number of the engine oil at each oil change interval.

5.3.2 Teardown

Overall, the engine appeared to be in excellent condition with individual component conditions considered better than or equivalent to diesel, as evaluated by the personnel at Cummins Intermountain Distributor. Notable excerpts of the teardown are summarized in Table 5-1. The full set of notes from the teardown can be found in Appendix E.

Table 5-1. Engine Teardown Inspection Notes.

Component	Condition
Cylinder Head	
Injectors	Less carbon than usual on all parts, less carbon than would be expected from diesel
Valves	Normal – do not need regrinding, deposits very low
Cam Shaft	Slight pitting on 2 lobes, others not a problem, normal wear
Cam Thrust Plate	Slight wear around outer edges – no wear on inner edge
Tappets	Some very slight pitting to match cam
Head Gasket	Good, no leakage, no coolant, no blow across
Block	
Main Bearings	Very good, no wear
Crankshaft	Slight seep of oil from rear main, slightly more than front. Exceptionally good journal condition, slight grooving at seals
Pistons	Clean, some deposits on top land
Rings	
Top	Even wear in center, no contact on edges, 10% each
2nd	25% face contact, clean
Oil	No apparent wear
Piston pins	No wear, normal
Liners	Honing marks apparent throughout, slight deposit on top land area
Rods	
Rod Bushings	Normal to no wear
Rod Bearings	Still within specs for reuse guidelines, but do show more than normal marking – somewhat like what is seen when coolant gets in the oil
Pumps	
Lube Pump	Some wear, normal
Fuel Lift Pump	Rust on strainer bolt, slight sediment on screen
Damper	Normal
Seals	
Front Crank Seal	Normal to less seepage than normal
Rear Crank Seal	Normal to some seepage from rear main
Injection Pump	#6 had heavy engine oil surrounding the lower end indicating leakage between the governor and the pump. #1 had a bad upper o-ring. In removing the other barrels, no other bad o-ring was found. All have a slight rusting of the barrel.
Exhaust Manifold	
Turbo	Good, no excess end play, tight

5.3.3 Engine Measurements

All critical engine measurements were within the published specification as printed in the Dodge Truck service manual. A summary of these measurements is given in Table 5-2, while a list of all the measurements done can be found in Appendix E.

5.3.4 Fuel Pump Inspection

Bosch found the internal pump components to be in good or very good condition. The plungers showed some fuel deposits, but not enough to cause sticking. Only an o-ring was found to be physically damaged but Bosch representatives attributed the damage to an assembly problem and said it was not fuel related. Bosch also reported that valve opening pressures for the injectors were slightly low, but not abnormal for the mileage of the engine. Bosch concluded that further testing needs to be performed to determine the effects of higher mileage on fuel related deposits in the pump. A copy of the fuel pump evaluation performed by Bosch is included in Appendix F.

Table 5-2. Engine Measurements.

Dimension	Maximum	Minimum	Cylinder (all values given in inches)					
			1	2	3	4	5	6
Cylinder bore	102.116 mm (4.0203 inch)	102.0 mm (4.0157 inch)	4.0160	4.0164	4.0164	4.0166	4.0166	4.0162
Cylinder Out-of round	0.038 mm (0.0015 inch)		0.0001	0.0002	0.0005	0.0006	0.0006	0.0002
Cylinder Taper	0.76 mm (0.003 inch)		0.0011	0.0006	0.0007	0.0000	0.0012	0.0010
Camshaft Journal		53.962 mm (2.1245 inch)	2.1258	2.1259	2.1260	2.1261	2.1260	2.1260
Camshaft Bore Diameter	54.133 mm (2.1312 inch)		2.1311	2.1300	2.1301	2.1298	2.1294	2.1296
Piston Pin Diameter		39.990 mm (1.5744 inch)	1.5745	1.5745	1.5745	1.5745	1.5745	1.5745
Piston Pin bore	40.025 mm (1.5758 inch)		1.5747	1.5749	1.5748	1.5750	1.5748	1.5749
Connecting rod pin bore	40.042 mm (1.5764 inch)		1.5748	1.5750	1.5748	1.5750	1.5751	1.5751
Connecting rod bore		Smallest diameter	2.7182	2.7191	2.7190	2.7202	2.7190	2.7198
Crankshaft Rod journal	69.013 mm (2.717 inch)	68.962 mm (2.715 inch)	2.7178	2.7174	2.7175	2.7167	2.7166	2.7179
Top Ring Gap	0.700 mm (0.0275 inch)	0.400 mm (0.0160 inch)	0.020	0.021	0.021	0.020	0.021	0.021
Intermediate Ring Gap	0.550 mm (0.0215 inch)	0.250 mm (0.0100 inch)	0.013	0.013	0.017	0.017	0.017	0.017
Oil Control Ring Gap	0.550 mm (0.0215 inch)	0,250 mm (0.0100 inch)	0.012	0.015	0.013	0.015	0.014	0.014
Crankshaft Main Journals	83.013 mm (3.2682 inch)	82.962 mm (3.2662 inch)	3.2672	3.2671	3.2670	3.2671	3.2672	3.2670

5.4 Conclusions

Results of the engine oil analysis, engine teardown inspection, engine component measurement, and fuel pump evaluations indicate that the engine did not experience excessive wear or deterioration as a result of using CEE as a fuel. Four oil tests showed significantly lower viscosity than the other tests. This was due to dilution coming off the lube oil by the fuel from the injector pump. Oil change intervals were shortened by about 1600 km (1000 miles) to solve this condition. Overall, the engine appeared to be in excellent condition with individual component conditions considered better than or equivalent to diesel

All critical engine measurements were within the published specification as printed in the Dodge Truck service manual. Bosch found the internal pump components to be in good or very good condition.

6. ENGINE EMISSIONS

The Truck-in-the-Park vehicle was emissions tested twice at the Los Angeles County Metropolitan Transportation Authority (LAMTA) Emissions Testing Facility (ETF).

The ETF, located in downtown Los Angeles, is a state-of-the-art laboratory specifically designed and built for the purpose of collecting exhaust emissions data from heavy-duty vehicles during transient chassis dynamometer operations. In addition to supplying data to the scientific community and private customers, the ETF provides exhaust emissions testing and data to California regulatory agencies in an effort to support the development of new emissions regulations for heavy-duty vehicles.

Several different biodiesel fuel blends were evaluated during the emissions testing program. This chapter reports on transient dynamometer tests of gaseous emissions at the LAMTA ETF with diesel on-road vehicles. The fuel used was vegetable oil esters produced by the Biological and Agricultural Engineering Department at the University of Idaho. Industrial-grade rapeseed was used to make the REE (and RME) for this testing instead of using the canola ethyl ester, which the truck used for most of this project. Canola (with low erucic acid content) is an edible form of rapeseed. REE was used for this testing to allow for comparison of results with previous work, and to be used as a control biodiesel fuel rather than using a biodiesel from an off-spec oil. Also, the off-spec canola oil had not yet been delivered when the startup emission tests were performed. Phillips 66, low-sulfur reference diesel fuel was tested as the control fuel to provide a baseline reference point. The first test took place at 5,955 km (3,700 mi.) and the final emissions test took place at 139,466 km (86,660 mi.).

6.1 Objectives

The objectives of the emissions tests were:

1) Obtain emissions data for 100 percent REE, and 50 percent and 20 percent blends of REE with diesel control fuel;

2) Compare regulated emissions data including total hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NOx), and particulate matter (PM), for REE, REE blends, and diesel control fuel;

3) Compare emission levels for the 1995 and 1998 tests using these fuels;

4) Determine baseline emissions data on the vehicle with and without the OEM catalytic converter; and to

5) Determine catalytic converter efficiency after operating for a long period of time on 100 percent REE.

6.2 Materials and Methods

The emissions tests were conducted at the LAMTA ETF located in Los Angeles, California. This facility has instrumentation to measure all regulated emissions: total hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NOx), and particulate matter (PM). The ETF provides quality assurance test results and calibrations in accordance with California Air Resources Board (CARB) quality assurance recommendations, (Dunlap, 1994).

6.2.1. Facilities

The ETF is equipped with a single 1.83 m (6 ft) diameter roll chassis dynamometer capable of testing single-axle or dual-axle vehicles from 2,268 kg (5,000 lbs) to 45,360 kg

(100,000 lbs) GVW. The facility is controlled by a computerized vehicle emissions testing system (VETS) that interfaces an exhaust sampling dilution tunnel, analyzer and computer software with the sampling and analysis of the exhaust gas emissions. The facility, emissions sampling hardware and integral software were designed and built to meet the requirements of the Code of Federal Regulations (CFR) Title 40, Part 86, "Control of air pollution from new and in-use motor vehicles and new and in-use motor vehicle engines: Certification and test procedures". The VETS is designed to perform exhaust emissions sampling and analysis to the requirements of the CFR for both compression ignition (CI) (diesel cycle) and spark ignition (SI) (Otto cycle) engines. The system permits the testing of vehicles over a variety of standardized operating conditions called drive cycles and a variety of vehicle load conditions.

6.2.2. Emissions Analyzers

Dunlap (1993) describes the test facility as follows:

The ETF's analytical system is composed of seven emissions analyzers. The hydrocarbon (HC) analyzer uses the principle of hydrogen flame ionization to measure hydrocarbons, and includes a complete Heated Flame Ionization Detector (HFID). This analyzer offers proven reliability for diesel testing where high-boiling hydrocarbons are present.

Nitrogen oxides (NOx) are measured using a chemiluminescent analyzer which monitors the chemiluminescent reaction of ozone (O_3) with nitric oxide (NO). This analyzer measures a wide range of NO and nitrogen dioxide (NO_2) concentrations with negligible interference from other gas components. The analyzer is equipped with an ozone generator,

which produces ozone (O_3) for the reactions with oxygen, or air using an ultraviolet ozone generating method.

Carbon monoxide (CO) and Carbon dioxide (CO_2) are measured using non-dispersive infrared (NDIR) detection. The ETF analytical bench is equipped with a total of four NDIR analyzers and is therefore able to measure both low and high concentrations of CO and CO_2.

Oxygen (O_2) concentrations are measured during raw, or non-dilute, testing using a magnetopneumatic sensing method. The analyzer provides an accurate and continuous determination of O_2 with negligible interference from other gaseous components.

PM is collected during the entire test cycle by diverting a portion of the exhaust through a secondary dilution tunnel, which contains collecting filters. The filters, which have been conditioned and weighed prior to testing per the CFR requirements, are re-weighed after the testing is completed to determine the amount of PM emissions in grams. The PM weight data are transferred to the VETS software where the grams per mile PM emissions data are generated based on exhaust flow through the filters for the applicable test.

It is noteworthy that the analyzers and equipment at the ETF functioned as expected and no problems were noted for the duration of the program.

6.2.3. Test Vehicle Installation

The vehicle had accumulated 5,955 km (3,700 mi.) at the time of the first test and 139,466 km (86,660 mi.) at the time of the second test. The weight used during the coast down and testing was 3,692 kg (8,140 lb.). The vehicle was driven from Moscow, Idaho, to Los Angeles, California, on 100 percent REE fuel for testing. Temperature and pressure

sensors were instrumented to the test vehicle engine and exhaust systems so that specified vehicle operating conditions could be monitored during testing.

The engine was not modified in any way for use with the vegetable oil fuels. The fuel delivery system was modified for convenience of changing fuels between test runs. Fuel delivery and fuel return lines were broken so that quick couplers could be installed. Individual 19-liter (5-gallon) fuel tanks were modified with fuel filter and flexible lines which could be connected to the quick couplers. During normal operation, fuel is delivered and returned to the vehicle tank. During testing the lines were disconnected from the main tank and connected to the external lines to which the correct test fuel was connected. For the tests, the fuel filter assembly mounted on the engine was removed and replaced with an aluminum block with internal connecting ports. This block was necessary to minimize the volume of fuel in the system when a fuel switch was required. Each tank of fuel had an individual fuel filter mounted on the tank.

Timed practice sessions with fuels of different colors showed that a minimum of 20 seconds was required for the return lines to be clear of the previous fuel. During actual testing, the return line was directed to a waste fuel tank while the engine was operated for 40-50 seconds at which time the return line was directed back into the test fuel tank. The low standard deviations in emissions data between tests of the same fuel is indicative of the success of the procedure for changing fuels.

6.2.4. ETF Quality Assurance

Standard operational quality assurance (QA) is conducted in accordance with the California Air Resources Board (CARB) recommended practices. This includes gas analyzer

six-point calibration, NO_x converter efficiency test, CVS injection, CO_2 interference, and HC hang-up checks. Additional equipment checks and QA, such as analyzer zero/span and analyzer purge and back-flush, are performed at the beginning and the conclusion of each emissions test. Due to the extended length of the tailpipe system to the dilution tunnel connection, a set-up test drive cycle was conducted as part of the QA for this program. This was conducted to verify the analyzer system operations and time delay and corrections were made as necessary.

6.2.5. Test Data Analysis

Emissions test data in units of grams per mile (gm/mile) are generated through the VETS for HC, CO, NO_x, CO_2, and PM. Fuel economy (FE) estimates were calculated and reported as described below. Three tests were completed for each fuel blend during both phases of vehicle configuration testing. The exhaust emission data are recorded and reported through the VETS. It is noteworthy that no anomalies were observed and no driver error occurred during any phase of this test program. The same driver and data collection staff were used in both sets of tests.

6.2.6. Test Cycle

The EPA Urban Dynamometer Driving Schedule for Heavy-Duty Vehicles was used as the test cycle for both the 1995 and 1998 tests. The EPA cycle has a total time of 1060 seconds and is shown graphically in Figure 6-1.

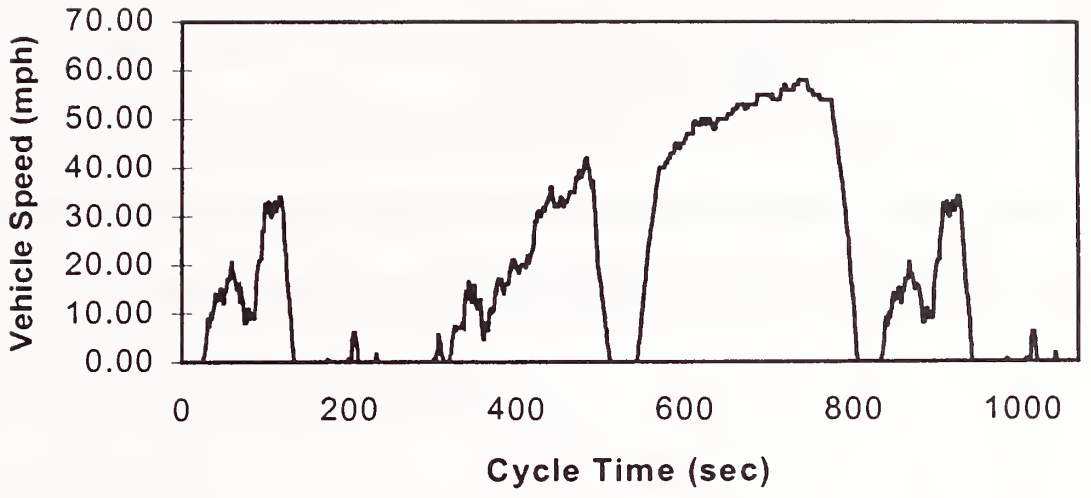

Figure 6-1. EPA Urban Dynamometer Driving Schedule for Heavy Duty Vehicles.

6.2.7. Road Load Simulation

In order to measure the emissions of a vehicle during operation, the actual driving conditions of the vehicle on the road must be simulated on the dynamometer. The dynamometer control system must simulate the force that would act on the vehicle if it were travelling on the road. This force, or Road Load (RL), is defined by the Equation 6-1, below, (Dunlap, 1994.).

$$RL = F_0 + F_1 V + F_2 V^n + I^{dv}/_{dt} + mg \sin(grad) \qquad \text{(eq. 6-1)}$$

where:

- RL = Road Load (force at roller surface)
- F_0 = Coefficient of friction force - independent of velocity
- F_1 = Coefficient of friction force - dependent on velocity
- F_2 = Coefficient of windage force (Drag coefficient)
- n = Velocity exponent
- V = Velocity at the roller surface

I = Vehicle Inertia (Dyno inertia plus appropriate amount of inertia as simulated by the control system)

$^{dv}/_{dt}$ = Acceleration

m = Vehicle Mass

g = Acceleration due to gravity

grad = Gradient in percent (%)

The EPA and Arterial test cycles do not include any gradients (uphill or downhill) therefore, the Road Load equation becomes Equation 6-2, shown below.

$$RL = F_0 + F_1V + F_2V^n + I^{dv}/_{dt} \qquad \text{(eq. 6-2)}$$

To aid in the development of a set of coefficients, University of Idaho personnel conducted coast down evaluations of the test vehicle in Idaho prior to the scheduled ETF test date. The results of this evaluation are presented in Figure 6-2.

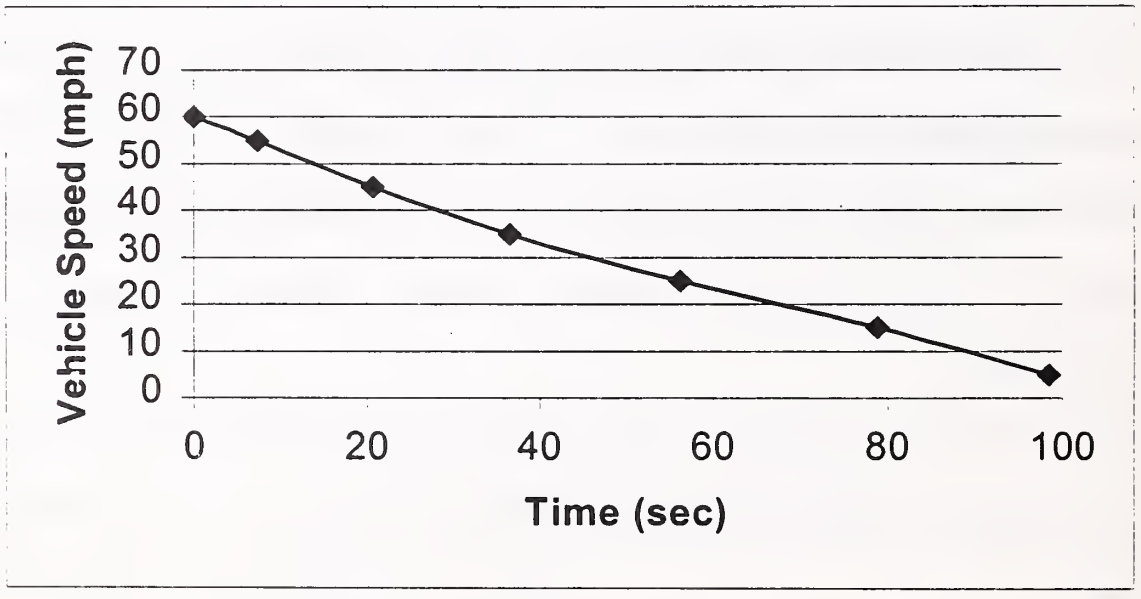

Figure 6-2. Coast down data for the 1995 Dodge used in the emissions test.

Based on the coast down data, LAMTA personnel developed a set of coefficients as a starting point for road load model development. Once the vehicle was installed on the dynamometer, coast downs were conducted and the model was refined to match the average on-road data. This refinement process was necessary to "factor out" the internal dynamometer resistance. The coefficients developed for this program for the 1995 Dodge were F_0 = 120 lbs., F_1 = 0.75 lbs/mph, F_2 = -0.0075 lbs/mph^2 and I = 8,140 lbs. Road gradient was 0 degrees throughout the tests.

6.2.8. Fuels Tested

Fuels tested during the course of the two years tests included:

(1) Phillips 2D low-sulfur diesel reference fuel (DIESEL or 2-D);

(2) 100 percent rapeseed ethyl ester (100REE);

(3) 50 percent REE - 50 percent diesel (50REE);

(4) 20 percent REE - 80 percent diesel (20REE);

The REE was produced in the Biological and Agricultural Engineering Laboratory at the University of Idaho using Dwarf Essex industrial rapeseed. Fuel characterization data are provided in Table 6-1 on the following page.

Table 6-1. Fuel Characterization Data

	50% REE/ 50% 2-D	20% REE/ 80% 2-D	100% REE	.05 Control 2-D
Conradson Carbon, %	0.02	0.02	0.02	NA*
Ash, %	0.003	0.003	0.004	.01
Sulfur, %	0.016	0.029	<0.005	.036
Carbon, %	83.02	84.53	82.15	86.75
Hydrogen, %	12.90	12.99	12.58	13.25
Oxygen, % by diff.	4.06	2.43	5.25	-
Nitrogen, ppm	25	41	2	NA
Cetane Rating	54.2	51	56.9	46.5
Flash Pt., PMCC, %	179	167	256	165
Particulate Matter, mg/L				
Total	1.02	0.40	4.4	8
Non-Combustible	0.6	0.18	1.82	
Copper Corrosion				
3 hrs. @ 122°F	Slight tarnish, 1A	Slight tarnish, 1A	Slight tarnish, 1A	Slight tarnish, 1A
Phosphorus, ppm	<0.004	0.014	0.015	-
Free Glycerin, wt. %	NA	NA	0.000	-
Monoglycerides, wt %	NA	NA	0.000†	-
Diglycerides, wt %	NA	NA	0.051	-
Triglycerides, wt %	NA	NA	0.000	-
Total Glycerin, wt %	NA	NA	0.008†	-

† The C. Plank method used for this determination under reports the amount of total glycerin in ethyl esters because of co-elution of ethyl esters and monoglycerides.

* NA = Not Available

6.2.9. Vehicle Instrumentation

The test vehicle was installed on the chassis dynamometer in accordance with typical ETF practice. A total of six pressure and temperature sensors were installed. The test sensors were oil pressure at the oil filter adapter housing, boost pressure at manifold, exhaust temperature at tailpipe adapter, fuel temperature at pump inlet, coolant temperature, and inlet air temperature.

6.2.10. Fuel Mass Flow Rate

Fuel consumption was determined by direct weighing. The fuel containers were placed on an electronic scale accurate to the nearest .02 pound. The weight of fuel was read at the start and end of each test. During the first test, this method had considerable error due to vibrations set up by running the truck because of the direct fuel line connection between the portable fuel tank on the scales, the fuel delivery and return lines and engine connections. For the second test, a bracket was made to tie the fuel lines down to the fuel stand to eliminate the vibrations that would affect the scale readings while the engine was running.

6.2.11. Test Design

Access to the test facility was scheduled for one week during which time all testing had to be completed. All runs for each fuel were tested in one group to reduce the "drift" of particulates through the dilution tunnel. The drift was important because toxicity studies were to be performed on the particulate samples and residual soot particles from previous runs could skew those results. This had the additional benefit of reducing the amount of time spent changing fuels and helped reduce the amount of waste fuel from line flushing. Ideally, fuels would have been randomized, but the concerns with particulate drift between tests with a high diesel concentration to one with high biodiesel concentration did not allow for this. The tests performed in 1995 and 1998 are outlined in Tables 6-2 and 6-3.

Table 6-2. Emissions Tests Performed, 1995

Block 1:With the Catalytic Converter:
Cold Start - 100% REE, 100% REE, 100% REE, 100% REE, Diesel
Diesel, Diesel,
Cold Start - Diesel, 20% REE, 20% REE 20% REE, 50% REE,
50% REE, 50% REE, 100% REE
Block 2:Without the Catalytic Converter
Cold Start - 100% REE, 100% REE, 100% REE, 100% REE, Diesel
Diesel, Diesel,
Cold Start - Diesel, 20% REE, 20% REE 20% REE, 50% REE,
50% REE

Table 6-3. Emissions Tests Performed, 1998

Block 1:With the Catalytic Converter:
Cold Start - 100% REE, 100% REE, 100% REE, 100% REE, Diesel
Diesel, Diesel,
Cold Start - Diesel, 20% REE, 20% REE 20% REE, 50% REE,
50% REE, 50% REE, 100% REE
Block 2:Without the Catalytic Converter
Cold Start - 100% REE, 100% REE, 100% REE, 100% REE, Diesel
Diesel, Diesel,
Cold Start - Diesel, 20% REE, 20% REE 20% REE, 50% REE,
50% REE, 50% REE, Diesel

6.2.12. Test Procedure

Although currently there are no standardized test procedures for heavy-duty vehicle chassis dynamometer emissions testing, the ETF has integrated the applicable requirements and guidelines of CFR 40, Part 86, Subpart B, "Emission Regulations for 1977 and Later Model Year New Light-Duty Vehicles and New Light-Duty Trucks; Test Procedures" and Subpart N, "Emissions Regulations for New Otto-Cycle and Diesel Heavy-Duty Engines: Gaseous and Particulate Exhaust Test Procedures." Specific test programs may vary from these guidelines as dictated and noted by the customer contract.

The test procedure was as follows:

1. The test fuel delivery tube was connected to the input line and the return line was connected to the waste tank. The engine was started and run for 50 seconds.

2. The engine was stopped and the return line was connected to the test fuel tank.

3. The vehicle was operated under load until the operating temperatures stabilized.

4. The test was started and the cycle completed.

5. While the technicians were taking data, weighing particulate filters, etc., the fuel system was switched to the next fuel to be tested.

Tests were conducted on March 20-24, 1995, and May 26-29, 1998. Twenty-eight EPA cycles including 4 cold start tests (one each morning) were completed in 1995. Thirty-one EPA cycles including 4 cold start tests were completed in 1998.

6.3 Results and Discussions

The only data presented in this paper are the emissions tests providing comparisons between the different fuels tested in 1995 and again in 1998. Data points were archived every 1-second during the test. Average and total values were calculated for cycles, phases, and overall. Thus the potential exists for additional analysis of test data. A general overview of the 1995 test compared to the 1998 test is shown in Figures 6-3 through 6-8. With the exception of PM, exhaust emissions were generally lowest with 100 percent REE when compared to diesel.

HC emissions generally decreased as the percentage of REE was increased in the fuel blend. The mean average emissions for HC for both the 1995 and 1998 tests both with and without the catalytic converter are shown graphically in Figure 6-3.

CO emissions decreased as the percentage of REE was increased regardless of the vehicle test configuration. In 1995, the decrease was less dramatic when increasing from 50REE to 100REE. CO emissions for both 1995 and 1998 tests with and without the catalytic converter are shown graphically in Figure 6-4.

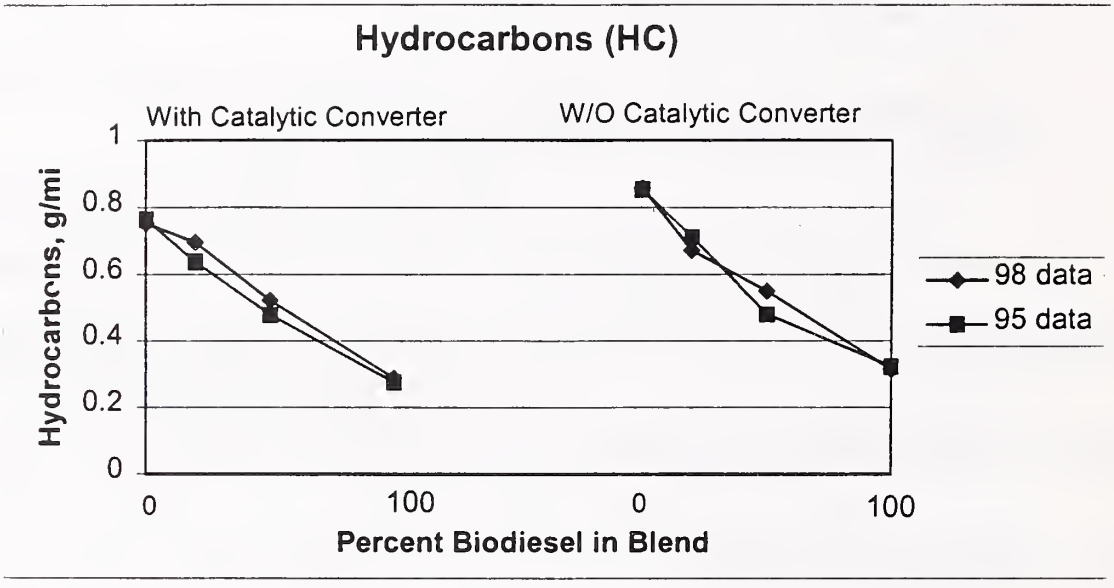

Figure 6-3. 1995 and 1998 data for HC for the EPA cycle and various blends of diesel and REE.

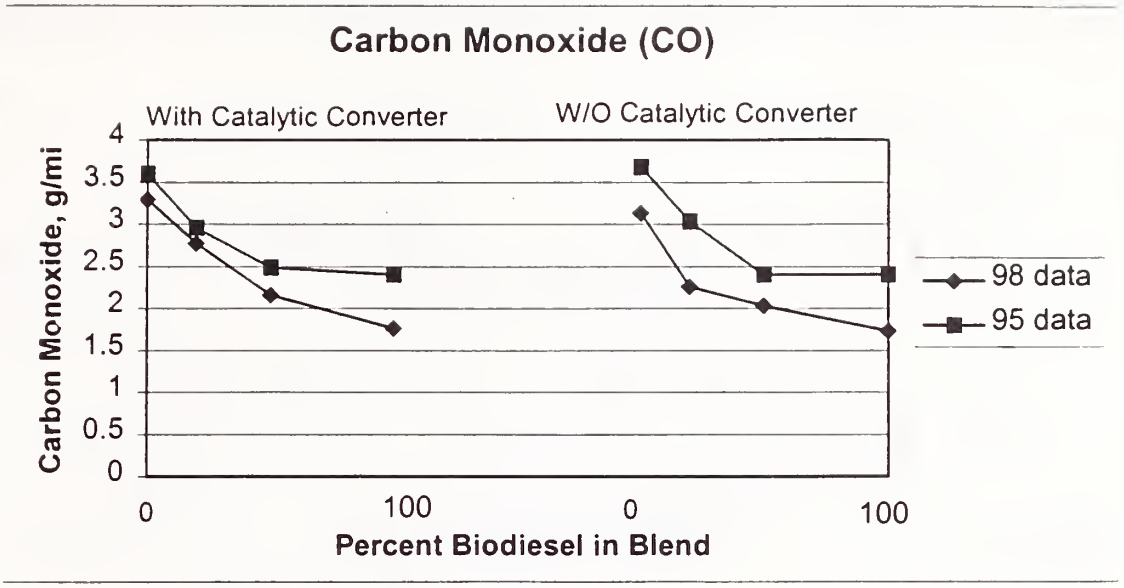

Figure 6-4. 1995 and 1998 data for CO for the EPA cycle and various blends of diesel and REE.

NO_x emissions decreased as the percentage of REE was increased with the catalytic converter installed on the vehicle. However, in 1995, NO_x emissions increased from the 20REE to 50REE when the vehicle was tested without the catalyst installed. NO_x emissions for both 1995 and 1998 with and without the catalytic converter are shown in Figure 6-5.

The percentage of REE had no significant effect on CO_2 emissions. CO_2 emissions for both 1995 and 1998 with and without the catalytic converter are shown graphically in Figure 6-6.

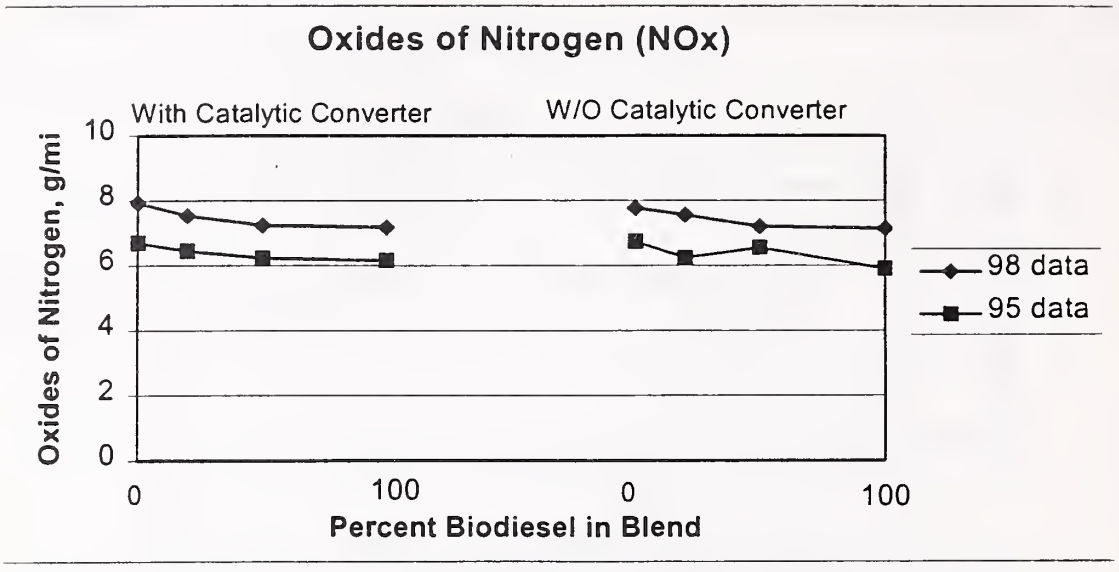

Figure 6-5. 1995 and 1998 data for NO_x for the EPA cycle and various blends of diesel and REE.

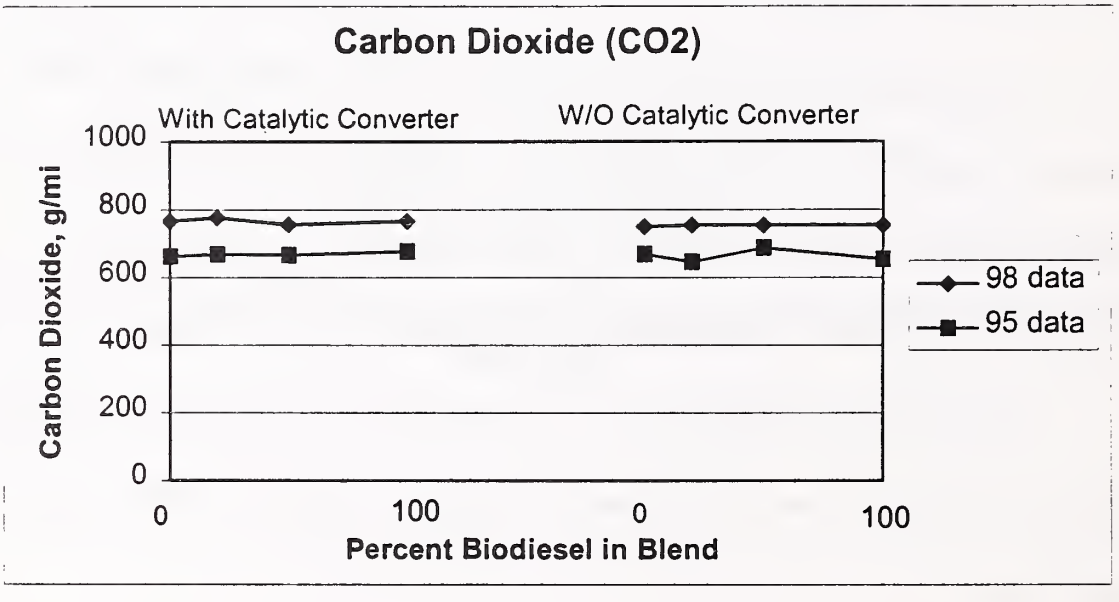

Figure 6-6. 1995 and 1998 data for CO_2 for the EPA cycle and various blends of diesel and REE.

PM emissions generally increased as the REE percent concentration was increased regardless of the vehicle test configuration. However, PM emissions were higher with the exhaust catalyst removed from the test vehicle, indicating the effect of the catalytic converter.

PM emissions for both 1995 and 1998 without the catalytic converter are shown graphically in Figure 6-7.

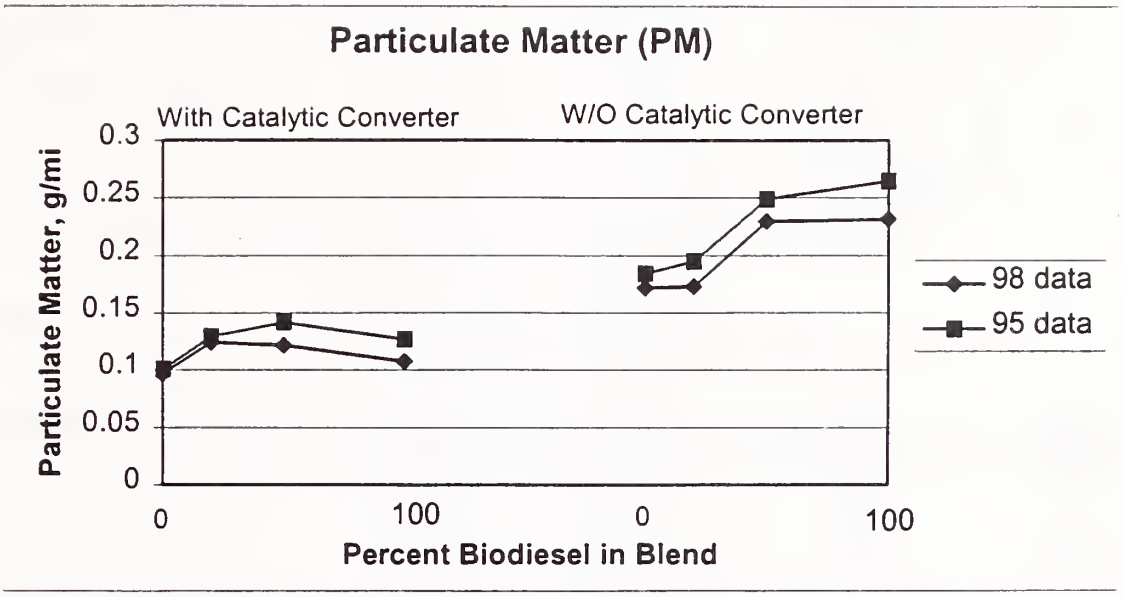

Figure 6-7. 1995 and 1998 data for PM for the EPA cycle and various blends of diesel and REE.

Figure 6-8 shows the fuel use data obtained by direct weighing. Fuel use increased as the REE percent concentration was increased regardless of the vehicle test configuration. This was expected due to the lower energy content of the ester fuels. Fuel use in the 1998 tests was significantly higher than the 1995 tests. There was no obvious reason for the increase in fuel use, but because the power was measured at the wheels, several factors, including increased drive train resistance, could have caused this difference.

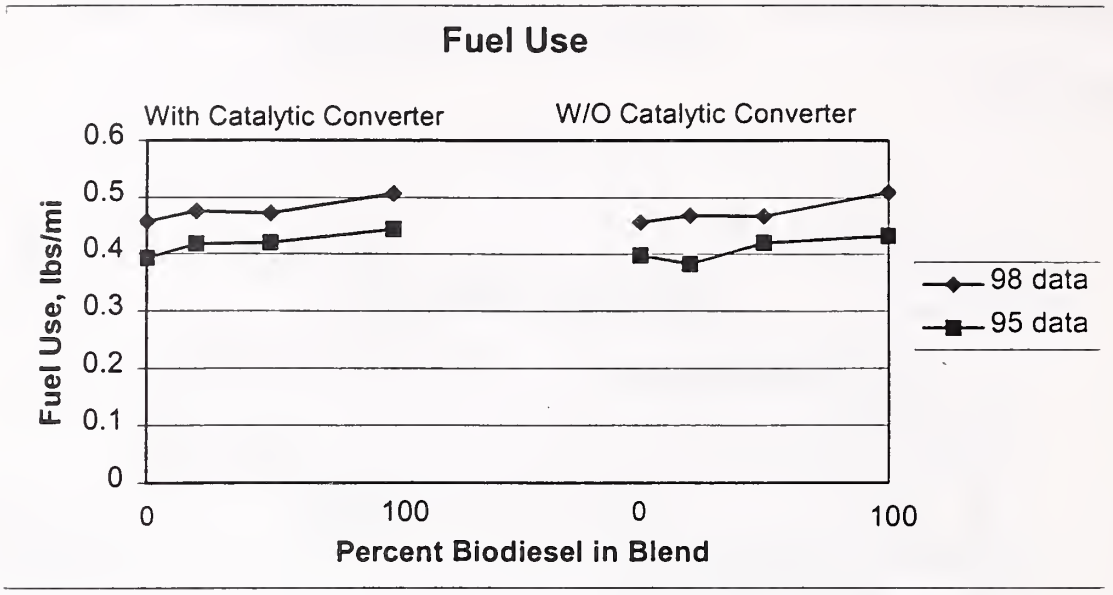

Figure 6-8. 1995 and 1998 fuel consumption data for the EPA cycle with various blends of diesel and REE.

In both tests, comparisons were made between blends of rapeseed oil ethyl ester and diesel reference fuel with and without the catalytic converter. Rapid comparisons are provided in the following tables and any desired absolute value can be found through multiplication. For clarity, Figures 6-3 through 6-8 were provided to give an overview of the data trends.

6.3.1. Analysis of 1995 Emissions Data

The data collected in 1995 for each of the regulated emission compounds are shown in Tables 6-4 through 6-7. The results shown in the tables are for diesel reference fuel, 20 percent REE, 50 percent REE and 100 percent REE. Tables 4 and 6 are in grams/mile and Tables 6-5 and 6-7 are normalized by dividing by the diesel level. For example, diesel/diesel is shown as 1.0 and the other fuels are relative to diesel. Thus, HC for 100 percent REE/diesel is 0.364, or 100 percent REE is about 36 percent of that from diesel.

Table 6-4. 1995 Emissions Data, EPA Cycle, with catalytic converter (gm/mile)

	HC	CO	Nox	CO2	PM
Diesel	0.763a	3.600a	6.697a	663.503a	0.101b
20REE	0.637b	2.960b	6.457b	668.147a	0.129a
50REE	0.480c	2.490c	6.243c	666.547a	0.142a
100REE	0.278d	2.405c	6.153c	677.483a	0.127a
Average	0.540	2.864	6.387	668.920	0.125

*Numbers in the same column followed by the same letter of the alphabet are not significantly different according to Fischer's protected LSD comparison.

Table 6-5. 1995 Emissions Data, EPA Cycle, with catalytic converter, ratios (blend value/diesel)

	HC	CO	Nox	CO2	PM
Diesel	1.000a	1.000a	1.000a	1.000a	1.000b
20REE	0.834b	0.822b	0.964b	1.007a	1.278a
50REE	0.628c	0.692c	0.932c	1.005a	1.403a
100REE	0.364d	0.668c	0.919c	1.021a	1.255a

*Numbers in the same column followed by the same letter of the alphabet are not significantly different according to Fischer's protected LSD comparison.

Table 6-6. 1995 Emissions Data, EPA Cycle, no catalytic converter (gm/mile)

	HC	CO	Nox	CO2	PM
Diesel	0.854a	3.683a	6.747a	669.540ab	0.184b
20REE	0.712b	3.033b	6.240b	646.550b	0.195b
50REE	0.483c	2.400c	6.550a	687.050a	0.249a
100REE	0.324d	2.403c	5.913c	654.813b	0.261a
Averages	0.593	2.880	6.363	664.488	0.222

*Numbers in the same column followed by the same letter of the alphabet are not significantly different according to Fischer's protected LSD comparison.

Table 6-7. 1995 Emissions Data, EPA Cycle, no catalytic converter, ratios (blend value/diesel)

	HC	CO	Nox	CO2	PM
Diesel	1.000a	1.000a	1.000a	1.000ab	1.000b
20REE	0.834b	0.824b	0.925b	0.966b	1.059b
50REE	0.565c	0.652c	0.971a	1.026a	1.352a
100REE	0.380d	0.652c	0.876c	0.978b	1.420a

*Numbers in the same column followed by the same letter of the alphabet are not significantly different according to Fischer's protected LSD comparison.

6.3.2. Analysis of 1998 Emissions Data

The data collected in 1998 for each of the regulated emission compounds are shown in Tables 6-8 through 6-10. The results shown in the tables are for diesel reference fuel, 20 percent REE, 50 percent REE and 100 percent REE. Tables 6-8 and 6-10 are in grams/mile and Tables 6-9 and 6-11 are normalized by dividing by the diesel level.

Table 6-8. 1998 Emissions Data for Rapeseed Ethyl Ester, EPA Cycle, with catalytic converter (gm/mile)

	HC	CO	Nox	CO2	PM
Diesel	0.753a	3.298a	7.943a	767.168a	0.097b
20REE	0.695b	2.773b	7.547b	776.527a	0.125a
50REE	0.522c	2.160c	7.250bc	756.307a	0.122a
100REE	0.290d	1.763d	7.188c	766.858a	0.108b
Averages	0.565	2.498	7.482	766.715	0.113

*Numbers in the same column followed by the same letter of the alphabet are not significantly different according to Fischer's protected LSD comparison.

Table 6-9. 1998 Emissions Data, EPA Cycle, with catalytic converter, ratios (blend value/diesel)

	HC	CO	Nox	CO2	PM
Diesel	1.000a	1.000a	1.000a	1.000a	1.000b
20REE	0.922b	0.841b	0.950b	1.012a	1.283a
50REE	0.693c	0.655c	0.913bc	0.986a	1.257a
100REE	0.385d	0.534d	0.905c	1.000a	1.109b

*Numbers in the same column followed by the same letter of the alphabet are not significantly different according to Fischer's protected LSD comparison.

Table 6-10. 1998 Emissions Data for REE, EPA Cycle, no catalytic converter (gm/mile)

	HC	CO	Nox	CO2	PM
Diesel	0.858a	3.133a	7.773a	749.273a	0.172b
20REE	0.671b	2.263b	7.553b	753.913a	0.173b
50REE	0.551c	2.030b	7.197c	754.357a	0.230a
100REE	0.316d	1.733c	7.133c	753.580a	0.232a
Averages	0.599	2.290	7.414	752.781	0.202

*Numbers in the same column followed by the same letter of the alphabet are not significantly different according to Fischer's protected LSD comparison.

Table 6-11. 1998 Emissions Data, EPA Cycle, no catalytic converter (blend value/diesel)

	HC	CO	Nox	CO2	PM
Diesel	1.000a	1.000a	1.000a	1.000a	1.000b
20REE	0.782b	0.723b	0.972b	1.006a	1.007b
50REE	0.642c	0.648b	0.926c	1.007a	1.338a
100REE	0.369d	0.553c	0.918c	1.006a	1.348a

*Numbers in the same column followed by the same letter of the alphabet are not significantly different according to Fischer's protected LSD comparison.

6.3.3. Comparison of 1995 vs. 1998 With and Without the Catalytic Converter

Tables 6-12 and 6-13 shows the comparison of the 1995 and 1998 tests; the numbers shown are the ratio of 1995 divided by 1998 for the EPA cycle for all test fuels with the catalytic converter. There was a significant difference between the 1995 and 1998 emissions levels for most fuels.

Table 6-12. 1995 and 1998 Comparison, EPA Cycle, with catalytic converter (ratio 1995/1998; a number of 1 indicates equal values each year)

	HC	CO	Nox	CO2	PM
Diesel	1.013	1.092*	0.843*	0.865*	1.041
20REE	0.917*	1.067*	0.856*	0.860*	1.037
50REE	0.919*	1.153*	0.861*	0.881*	1.161*
100REE	0.959	1.365*	0.856*	0.883*	1.178*

*Numbers followed by an asterisk imply a significant difference between 1995 and 1998 for that comparison according to Fischer's protected LSD ($p < 0.05$).

Table 6-13. 1995 and 1998 Comparison, EPA Cycle, no catalytic converter (ratio 1995/1998; a number of 1 indicates equal values each year)

	HC	CO	NOx	CO2	PM
Diesel	0.995	1.176*	0.868*	0.894*	1.072
20REE	1.061*	1.340*	0.826*	0.858*	1.127*
50REE	0.876*	1.182*	0.910*	0.911*	1.083*
100REE	1.025	1.387*	0.829*	0.869*	1.129*

*Numbers followed by an asterisk imply a significant difference between 1995 and 1998 for that comparison according to Fischer's protected LSD ($p < 0.05$).

6.3.4. Comparison of Catalytic Converter vs. No Catalytic Converter

Tables 6-14 and 6-15 shows the comparison of the 1995 and 1998 test data with and without the OEM catalytic converter for the same fuels as reported in the other tests. The catalytic converter reduced HC and PM emissions, with PM emissions being most heavily affected.

Table 6-14. Comparison of 1995 EPA cycle with and without catalytic converter (ratio With Converter/Without Converter; a number of 1 indicates no change)

	HC	CO	NOx	CO2	PM
Diesel	0.894*	0.977	0.993	0.991	0.549*
20REE	0.895*	0.976	1.035*	1.033*	0.663*
50REE	0.994	1.038	0.953*	0.970*	0.570*
100REE	0.857*	1.001	1.040*	1.035*	0.485*

*Numbers followed by an asterisk imply a significant difference between with the catalytic converter and without the catalytic converter for that comparison according to Fischer's protected LSD ($p < 0.05$).

Table 6-15. Comparison of 1998 EPA cycle with and without the catalytic converter (ratio With Converter/Without Converter; a number of 1 indicates no change)

	HC	CO	NOx	CO2	PM
Diesel	0.878*	1.053	1.022	1.024	0.565*
20REE	1.035	1.225*	0.999	1.030*	0.720*
50REE	0.947	1.064	1.007	1.003	0.531*
100REE	0.917	1.017	1.008	1.018	0.465*

*Numbers followed by an asterisk imply a significant difference between with the catalytic converter and without the catalytic converter for that comparison according to Fischer's protected LSD ($p < 0.05$).

6.3.5. Comparison of Cold Start vs. Hot Start Tests

In 1995 and 1998, one cold start test was conducted each test day. Two cold start tests were conducted with the catalytic converter and two without the catalytic converter. Tables 6-16 and 6-17 are relative comparisons between the cold start data and the hot start data for each of the fuels tested.

Table 6-16. Comparison of 1995 EPA cycle cold and hot starts.
(Average of with and without catalytic converter.)
(ratio 1995 Cold Start/1995 Hot Start; a number of 1 indicates no change)

	HC	CO	NOx	CO2	PM
Diesel	1.326	2.042	0.951	1.139	2.074
REE	1.961	1.947	1.359	1.147	1.665
Average	1.643	1.994	1.155	1.143	1.870

*Insufficient data for statistical comparison

Table 6-17. Comparison of 1998 EPA Cycle cold and hot starts.
(Average of with and without catalytic converter.)
(ratio 1998 Cold Start/1998 Hot Start; a number of 1 indicates no change)

	HC	CO	NOx	CO2	PM
Diesel	2.386	2.336	1.084	1.122	2.815
REE	2.114	1.622	1.054	0.803	1.749
Average	2.250	1.979	1.069	0.963	2.282

*Insufficient data for statistical comparison's

6.3.6. General Observations for Emissions Data

These data show a significant reduction in HC, CO, and NOx as percent of vegetable oil is increased and a non-significant increase in PM. The PM data had the most variability of the data and an examination of the raw data shows that there is scatter sufficient to neutralize differences.

These data show that HC levels for 100REE were reduced by more than 60 percent compared to the 2-D levels and CO levels for 100REE were reduced by more than 50 percent compared to the 2-D levels. The CO_2 showed no significant differences for any fuel tested. NOx was generally decreased with increasing ester. PM generally increased with increasing ester in the fuel blend.

It has generally been found that the fatty acid esters increase NOx and decrease PM; however in these tests, generally speaking, the reverse was true. One might speculate that

this trend is due to the fatty acid constituents of rapeseed esters tested or that it is a characteristic of this particular engine. Also, most other emissions tests involving esters used a PTO engine test cycle instead of a chassis test. Cycle differences and test condition differences between the driving cycle and the PTO cycle could possibly influence NOx formation. In either case, the results were consistent for both years of testing.

The catalytic converter had a consistently significant effect on the PM and HC emissions, reducing PM by approximately 50 percent for 100REE. It is interesting to note that the efficiency of the OEM catalytic converter was not affected by the long-term use of ethyl esters in this engine.

6.4 Conclusions

Specific conclusions of the emissions study are:

1. HC and CO decreased as the percentage of REE was increased. PM generally increased with increased REE and there was no statistically significant change in CO_2 for any of the fuels. HC decreased nearly linearly with blend of biodiesel, while CO had most of its decrease in the 0-50 percent blend range.

2. NOx decreased as the percentage of REE was increased in the fuel with the exception of the 50 percent REE data point in 1995 without a catalytic converter.

3. HC emissions for 100REE were only 36 percent of diesel in 1995 and 39 percent of diesel in 1998 with the catalytic converter installed. HC emissions for 100REE were 38 percent of diesel in 1995 and 37 percent of diesel in 1998 without the catalytic converter installed. HC emissions were only slightly affected by the presence of the catalytic converter.

4. CO emissions for 100REE were only 67 percent of diesel in 1995 and 53 percent of diesel in 1998 with the catalytic converter installed. Without the catalytic converter installed, 100REE emissions were 65 percent of diesel in 1995 and 55 percent of diesel in 1998. CO is not significantly affected by the catalytic converter.

5. NOx emissions for 100REE were reduced to 92 percent of diesel in 1995 and 91 percent of diesel in 1998 with the catalytic converter installed. NOx emissions were

reduced to 88 percent of diesel in 1995 and 92 percent of diesel in 1998 without the catalytic converter installed.

6. CO_2 emissions were not significantly different for fuels tested in 1995 or 1998, but CO_2 emissions were significantly different between 1995 and 1998 tests for the same fuels. CO_2 production is a factor of the quantity of fuel used and carbon chain length of the molecule.

7. PM emissions for 100REE compared to diesel were increased 26 percent in 1995 and 11 percent in 1998 with the catalytic converter installed. Without the catalytic converter installed, PM emissions for 100REE were 42 percent higher than diesel in 1995 and 35 percent higher than diesel in 1998. Overall, the catalytic converter reduced PM by over 50 percent for 100REE. The catalytic converter had more effect on REE PM emissions than the emissions from any other fuel.

8. Cold start data were limited, but they show that HC, CO, and PM seemed to increase more for diesel cold starts than REE cold starts compared to hot starts with the same fuel.

9. Fuel consumption increased by 14 percent from 1995 to 1998.

In this study, NOx was lower and PM was higher with biodiesel when compared to 100 percent diesel. This contradicts many previous engine tests with biodiesel which typically show NOx emissions from biodiesel higher with a corresponding decrease in PM. This critical difference may be due to the type of dynamometer tests performed. This test was a chassis driving test where the vehicle is rarely driven at or near 100 percent of its maximum power or torque. This is due to the high power to weight ratio on a pickup truck as compared to a heavy duty truck. The FTP for engine or PTO dynamometer testing outlines the procedure to "map" the engine's maximum torque and power. The specified dynamometer target points on the cycle are then derived from these maximum values. As a result, the engine dynamometer test loads the engine near its maximum load more often resulting in a different emissions profile. The higher NOx and reduced PM from biodiesel tested with an engine dynamometer is due to this higher loading.

7 OVERALL SUMMARY AND CONCLUSIONS

Summaries and conclusions of each of the previous sections of this report are summarized below.

7.1 Fuel Production and Quality Assurance

The fuel used for the test is Canola Ethyl Ester (CEE). The base canola oil for this fuel was supplied by Koch Agri-Services of Great Falls, Montana. It was an off-spec oil which was deemed unsuitable for human consumption. The esters were produced with ethanol from waste potatoes provided by the J.R. Simplot Company of Caldwell, Idaho. The fuel was delivered in a total of 7 lots of about 3000-3800 liters (800-1000 gallons) each over a period of two years in 1040 liter (275 gallon) totes. The total amount of fuel delivered was 23,076 liters (6,096 gallons). The fuel was stored in a 37,850 liter (10,000 gallon) storage tank at Mammoth Hot Springs. Each batch of fuel delivered to the Park Service was analyzed for quality and consistency with a summary presented in Table 3-1.

7.2 Engine Performance Testing

Performance of the engine varied, but the vehicle did not experience a sustained reduction in power over time. Vehicle testing also showed that REE has slightly less power than diesel which is expected due to the lower energy of the REE fuel per volume. Cylinder compression varied from 450 psi to 500 psi, but individual cylinders didn't vary by more than 7 percent of the average for that particular test. The injector valve opening pressures tended to decrease over time. Intermountain Cummins also reported lower than normal injector valve opening pressures. Bosch reported that valve opening pressures were low, but

not abnormal for the mileage of the engine. The borescope inspections did not show any evidence of excessive coking or premature wear of the engine.

7.3 Engine Teardown and Durability Analysis

Results of the engine oil analysis, engine teardown inspection, engine component measurement, and fuel pump evaluations indicate that the engine did not experience excessive wear or deterioration as a result of using CEE as a fuel. Four oil tests showed significantly lower viscosity than the other tests. This was due to fuel diluting the lube oil through a cracked O-ring in the injector pump. Oil change intervals were shortened by about 1600 km (1000 miles) to solve this condition. Overall, the engine appeared to be in excellent condition with individual component conditions considered better than or equivalent to diesel. All critical engine measurements were within the published specification as printed in the Dodge Truck service manual. Bosch found the internal pump components to be in good or very good condition.

7.4 Engine Emissions

HC and CO decreased and PM increased as the percentage of REE was increased. NOx generally decreased as the percentage of REE increased. Fuel consumption increased by 14 percent from 1995 to 1998. CO_2 emissions were not significantly different for different fuels tested in 1995 or 1998, but CO_2 emissions were significantly different between 1995 and 1998 tests for the same fuels which coincides with the increase in fuel consumption. Cold start data were limited, but it shows that HC, CO, and PM seemed to increase more for diesel cold starts than REE cold starts compared to hot starts with the same fuel. There was no

deterioration of the catalytic converter's efficiency with the use of biodiesel over long periods of time.

In this test, NOx was lower and PM was higher with biodiesel when compared to 100 percent diesel. This contradicts many previous engine tests with biodiesel which typically show NOx emissions from biodiesel higher with a corresponding decrease in PM. This critical difference may be due to the type of dynamometer tests performed. This test was a chassis driving test where the vehicle is rarely driven at or near 100 percent of its maximum power or torque. This is due to the high power to weight ratio on a pickup truck as compared to a heavy duty truck. The FTP for engine or PTO dynamometer testing outlines the procedure to "map" the engine's maximum torque and power. The specified dynamometer target points on the cycle are then derived from these maximum values. As a result, the engine dynamometer test loads the engine near its maximum load more often, resulting in a different emissions profile. The higher NOx and reduced PM from biodiesel tested with an engine dynamometer is due to this higher loading.

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Appendix A

Fuel delivery trip reports

Trip Summary Report #1

Date	Summary
April 3, 1995	Daryl Reece and Chuck Peterson left Moscow, Idaho and traveled to Bozeman, Montana and stayed the night.
April 4, 1995	Drove to Mammoth, Wyoming and transferred Biodiesel from totes to the Park Service Biodiesel fuel tank. Picked up tools and supplies from LAMTA trip. Drove to Helena, Montana and stayed the night.
April 5, 1995	Attended the project kickoff on the Montana State Capitol building grounds. Chuck Peterson flew to Moscow, Idaho. Daryl Reece drove to Great Falls, Montana, Koch Agri Services and loaded three totes and 2 55-gallon drums with degummed rapeseed oil for a total of 845 gallons. Drove to Moscow, Idaho.

Trip Summary Report #2

Date	Summary
June 1, 1995	Todd Hustrulid left Moscow, Idaho with 800 gallons of Biodiesel and traveled to Livingston, Montana and stayed the night.
June 2, 1995	Todd Drove to Mammoth, Wyoming and dropped off the trailer with 800 gallons of Biodiesel. Todd went to a wedding and the Park Service unloaded 525 gallons of Biodiesel.
June 5, 1995	Todd picked up the trailer with the remaining 225 gallons of fuel and drove to Moscow, Idaho.

Trip Summary Report #3

Date	Summary
July 12, 1995	Daryl Reece and Jeffrey Taberski left Moscow, Idaho and travelled to Gardiner, Montana and stayed the night.
July 13, 1995	Drove to Mammoth, Wyoming. Filled the Biodiesel storage tank located at the YNP Service Garage. Transferred the remaining Biodiesel to the Park Service's 10,000 gallon storage tank. Drove to Moscow, Idaho.
Total distance:	1108 miles.
Biodiesel Delivered:	880 gallons.

Trip Summary Report #4

Date	Summary
July 20, 1995	Jeffrey Taberski and Joe Thompson left Moscow, Idaho and travelled to Gardiner, Montana and stayed the night.
July 21, 1995	Drove to Mammoth, Wyoming and transferred Biodiesel from three totes to the Park Service's 10,000 gallon storage tank. Drove to Moscow, Idaho.
Total distance:	1162 miles.
Biodiesel Delivered:	825 gallons.

Trip Summary Report #5

Date	Summary
August 6, 1995	Daryl Reece and Jeffrey Taberski left Moscow, Idaho and traveled to Mammoth, Wyoming, leaving the fuel trailer at the Park Service maintenance facility. Drove to Billings, Montana and stayed the night.
August 7, 1995	Met with Jim Evanoff at Tractor & Equipment in Billings, Montana to perform dynamometer, injector, compression, and borescope tests on the Park Service's '95 Dodge truck. Stayed the night in Billings, Montana.
August 8, 1995	Attended the Big Sky AFV Conference & Expo in Billings, Montana where the '95 Dodge was on display. Picked up the University's '94 Dodge truck and drove back to Mammoth, Montana to unload three totes and two 55-gallon drums of Canola Ethyl Ester for a total of 935 gallons. Daryl Reece drove to Deer Lodge, Montana and stayed the night. Jeffrey Taberski drove to Moscow, Idaho.
August 9, 1995	Daryl Reece drove to Moscow, Idaho.
Total distance:	1387 miles.
Biodiesel Delivered:	935 gallons.

To: Howard Haines
Bioenergy Engineer
Montana Department of Environmental Quality

From: C.L. Peterson, Professor
Daryl Reece, Biodiesel Engineer
Jeffrey Taberski, Graduate Student

Date: May 29, 1996

Subject: Trip and fuel delivery report

****

Trip Report

Date	Summary
May 19, 1996	Daryl Reece left Moscow with the 94 Dodge Pickup and trailer with 3 totes and 2 barrels of fuel (933 gallons). Jeffrey Taberski and Brian Hammond left Moscow with the 92 Ford Pickup and 2 barrels of fuel (108 gallons).
May 20, 1996	Assist with preparations for conference, "Commercialization of Biodiesel: Environmental and Health Benefits." in Mammoth Hot Springs, Yellowstone National Park. Transferred 473 gallons of fuel to the Park Service's 10,000 gallon storage tank.
May 21, 1996	Attended conference
May 22, 1996	Attended conference Transferred 200 gallons of fuel to the '95 Dodge's onboard storage tank, and 350 gallons to the Con Vault tank at the maintenance garage.
May 23, 1996	Brian Hammond left for Moscow via Boise, Idaho. Daryl Reece left for Moscow via Caldwell, Idaho. Jeffrey Taberski left for and arrived in Moscow with another party.

May 24, 1996 Daryl Reece arrived in Moscow.
Brian Hammond arrived in Moscow.

Fuel Delivery Report

'92 Ford F-250 Biodiesel Truck

Fuel delivered:	2 bbl@54gal/bbl
Total fuel delivered:	108 gallons
Total miles travelled:	1566 miles

'94 Dodge 2500 Biodiesel Truck

Fuel delivered:	(3 totes@275gal/tote + 2bbl@54 gal/bbl)
Total fuel delivered:	933 gallons
Total miles travelled:	1602 miles

To: Howard Haines
Bioenergy Engineer
Montana Department of Environmental Quality

From: C.L. Peterson, Professor
Jeffrey Taberski, Graduate Student

Date: October 28, 1996

Subject: Trip and fuel delivery report

****

Date	Summary
10/4/96	Jeff Taberski left Moscow, arrived in Gardiner, MT and stayed the night.
10/5/96	Jeff Taberski traveled to Mammoth Hot Springs and pumped 820 gallons of Biodiesel into the main 10,000 gallon storage tank. He then left for Moscow, ID. Jeff Taberski arrived in Moscow, ID.

Delivery Vechicle Used:	1994 Dodge Biodiesel pickup
Total Miles Driven:	1125 miles
Total Fuel Delivered:	820 gallons

Appendix B

Fuel Properties Reports

- Phoenix Chemical Labs
- Diversified Laboratories

TELEPHONE 312-772-3577
FAX NO 708-864-7356

Phoenix Chemical Laboratory, Inc.

FUEL AND LUBRICANT TECHNOLOGISTS
3953 SHAKESPEARE AVENUE
CHICAGO, ILL. 60647-3497

April 24, 1995

RECEIVED FROM University of Idaho
JML 85
Moscow, ID 83844-2040

SAMPLE OF Rapeseed Ethyl Ester (REE) (on 2) LABORATORY NO 5 4 10 44

MARKED Lot 1 Yellowstone

Water & Sediment, %	0.01
Ramsbottom Carbon, as received (Note 1)	0.062
Ash, %	0.011
Sulfur, %	0.022
Cetane Rating (ASTM D613)	59.5
Copper Corrosion, 3 hrs @ 122°F	slight tarnish 1A
Karl Fischer Water, ppm	757
Particulate Matter, mg/L	
Total	2.44
Non-combustible	0.40
Nitrogen, ppm	14
Carbon, %	77.15
Hydrogen, %	9.52
Oxygen, % (by difference)	
Iodine No.	97.5

Distillation (ASTM D86)	Temperature, °F
Initial Boiling Point	440
5%	570
10%	Distillation discontinued due to cracking

Note 1: R-carbon run as received because sample was non-distillable.

Arthur A. Krawetz

PHOENIX CHEMICAL LABORATORY, INC.
REC

TELEPHONE 312-772-3577
FAX NO 708-864-7356

Phoenix Chemical Laboratory, Inc.

FUEL AND LUBRICANT TECHNOLOGISTS
5954 SHAKESPEARE AVENUE
CHICAGO, ILL. 60647-3497

July 11, 1995

RECEIVED FROM University of Idaho
JML 85
Moscow, ID 83844-2040

SAMPLE OF Rapeseed Ethyl Ester (REE) (on 2) LABORATORY NO. 5 6 9 27

MARKED Lot 2 Yellowstone

Water & Sediment, %	Trace(<0.005)
Ramsbottom Carbon, as received (Note 1)	0.05
Ash, %	0.003
Sulfur, %	0.019
Cetane Rating (ASTM D613)	58.4
Copper Corrosion, 3 hrs @ 122°F	slight tarnish 1A
Karl Fischer Water, ppm	795
Particulate Matter, mg/L	
Total	1.97
Non-combustible	0.56
Nitrogen, ppm	5
Carbon, %	78.16
Hydrogen, %	12.42
Oxygen, % (by difference)	9.42
Iodine No.	94.8
Distillation (ASTM D86)	**Temperature, °F**
Initial Boiling Point	510
5%	Distillation discontinued due to cracking

Note 1: R-carbon run as received because sample was non-distillable.

Arthur A. Krawetz

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FAX NO 708-864-7356

Phoenix Chemical Laboratory, Inc.

FUEL AND LUBRICANT TECHNOLOGISTS
3953 SHAKESPEARE AVENUE
CHICAGO, ILL. 60647-3497

August 11, 1995

RECEIVED FROM University of Idaho
JML 85
Moscow, ID 83844-2040

SAMPLE OF Rapeseed Ethyl Ester (REE) (on 2)

LABORATORY NO 5 7 25 35

MARKED Lot 3 Yellowstone

Water & Sediment, %	Nil (<0.005)
Ramsbottom Carbon, %	0.069
Ash, %	0.002
Sulfur, %	<0.005
Cetane Rating	56.9
Copper Corrosion (3 hrs. @ 122°F)	Slight Tarnish 1A
Karl Fischer Water, ppm	1090
Particulate Matter, mg/L	
total	1.00
non-combustible	0.03
Nitrogen, %	0.0031
Carbon, %	77.31
Hydrogen, %	9.45
Oxygen, % (by difference)	13.24
Iodine No.	109

PHOENIX CHEMICAL LABORATORY, INC. REG

TELEPHONE 312-772-3577
FAX NO 708-864-7356

Phoenix Chemical Laboratory, Inc.

FUEL AND LUBRICANT TECHNOLOGISTS
4953 SHAKESPEARE AVENUE
CHICAGO, ILL. 60647-3497

August 11, 1995

RECEIVED FROM University of Idaho

SAMPLE OF Rapeseed Ethyl Ester (REE) (on 2)

LABORATORY NO. 5 7 25 35

MARKED Lot 3 Yellowstone

Cont page 2 of 2

Distillation (ASTM D86)

Distillation	Temperature, °F
Initial Boiling Point	570
5%	610
10%	620
20%	634
30%	640
40%	645
50%	650
60%	Note

Note: Distillation discontinued due to cracking.

Arthur A. Krawetz

TELEPHONE 312-772-3577
FAX NO. 708-864-7356

ATTN: DARREL REECE

Phoenix Chemical Laboratory, Inc.

FUEL AND LUBRICANT TECHNOLOGISTS
3993 SHAKESPEARE AVENUE
CHICAGO, ILL. 60647-3497

November 3, 1995

RECEIVED FROM University of Idaho
AG Engr 056-K200 416948
Moscow, ID 83844-2040

SAMPLE OF Canola Ethyl Ester (CEE) LABORATORY NO. 5 9 22 68

MARKED Yellowstone #4

Water & Sediment, %	0.02
Ramsbottom Carbon, %	0.07
Ash, %	0.002
Sulfur, %	Trace (<0.005)
Cetane Rating	55.3
Copper Corrosion (3 hrs. @ 122°F)	Slight Tarnish 1A
Karl Fischer Water, ppm	1108
Particulate Matter, mg/L	
total	8.90
non-combustible	<0.01
Carbon, %	77.10
Hydrogen, %	9.80
Oxygen, % (by difference)	13.1
Iodine No.	113.7

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Phoenix Chemical Laboratory, Inc.

FUEL AND LUBRICANT TECHNOLOGISTS
3953 SHAKESPEARE AVENUE
CHICAGO, ILL. 60647-3497

November 3, 1995

RECEIVED FROM University of Idaho

SAMPLE OF Canola Ethyl Ester (CEE) LABORATORY NO. 5 9 22 68

MARKED Yellowstone #4

Cont page 2 of 2

Vacuum Distillation

Distillation	Temperature °F @ 1.0 mm Hg.	°F @ 760 mm Hg
Initial Boiling Point	300	656
5%	335	709
10%	335	700
20%	336	702
30%	342	709
40%	342	709
50%	342	709
60%	342	709
70%	342	709
80%	344	712
90%	347	716
End Point	459	854
Received		94.5
Residue		3.8
Loss		1.7

Arthur A. Krawetz

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FAX NO. 708-864-7356

Phoenix Chemical Laboratory, Inc.

FUEL AND LUBRICANT TECHNOLOGISTS
3953 SHAKESPEARE AVENUE
CHICAGO, ILL. 60647-3497

November 13, 1995

RECEIVED FROM University of Idaho
AG Engr 056-K200 416948
Moscow, ID 83844-2040

SAMPLE OF Rapeseed Ethyl Ester (REE) LABORATORY NO. 5 8 30 22

MARKED Yellowstone #5

Water & Sediment, %	nil
Ramsbottom Carbon, %	0.054
Ash, %	0.002
Sulfur, %	<0.001
Cetane Rating	55.2
Copper Corrosion (3 hrs. @ 122°F)	Slight Tarnish 1A
Karl Fischer Water, ppm	1095
Particulate Matter, mg/L	
total	0.89
non-combustible	0.28
Carbon, %	77.07
Hydrogen, %	12.04
Oxygen, % (by difference)	10.89
Iodine No.	110.7
Nitrogen, ppm	14

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FAX NO 708-864-7356

Phoenix Chemical Laboratory, Inc.

FUEL AND LUBRICANT TECHNOLOGISTS
3953 SHAKESPEARE AVENUE
CHICAGO, ILL. 60647-3497

November 13, 1995

RECEIVED FROM University of Idaho

SAMPLE OF Rapeseed Ethyl Ester (REE) LABORATORY NO. 5 8 30 22

MARKED Yellowstone #5

Cont page 2 of 2

Vacuum Distillation

Distillation	Temperature oF @ 1.0 mm Hg.	oF @ 760 mm Hg.
Initial Boiling Point	164	479
5%	296	651
10%	331	695
20%	332	696
30%	334	699
40%	334	699
50%	335	700
60%	337	703
70%	342	709
80%	345	713
90%	350	719
95%	359	730
End Point	406	790
Received		96.0
Residue		2.7
Loss		1.3

Arthur A. Krawetz

TELEPHONE 312-772-3577
FAX NO. 847-864-7356

Phoenix Chemical Laboratory, Inc.

FUEL AND LUBRICANT TECHNOLOGISTS
5955 SHAKESPEARE AVENUE
CHICAGO, ILL. 60647-3497

June 25, 1996

RECEIVED FROM University of Idaho
Bio & AG Engr. Peterson
Moscow, ID 83844-2060

SAMPLE OF Biodiesel Fuel
(CEE)

LABORATORY NO 6652

MARKED Yellowstone #6
5/7/96

Water & Sediment, % (v/v)	nil
Ramsbottom Carbon as received, %	0.05
Ash, %	0.003
Sulfur, %	<0.005
Carbon, %	80.74
Hydrogen, %	12.25
Oxygen %, by difference	7.01
Nitrogen, ppm	78
Cetane Rating	59.8
Iodine No.	111.0
Particulate Matter, mg/L	
Total	1.59
Non-Combustible	0.51
Copper Corrosion, 3 hrs. @ 122°F	slight tarnish, 1A
Phosphorus, mg/L	0.2

Distillation

	Temperature, °F
Initial Boiling Point	568
5%	590
10%	Distillation discontinued due to cracking.

Arthur A. Krawetz

TELEPHONE 773-772-3577
FAX NO. 847-864-7356

Phoenix Chemical Laboratory, Inc.

FUEL AND LUBRICANT TECHNOLOGISTS
3953 SHAKESPEARE AVENUE
CHICAGO, ILL. 60647-3497

December 3, 1996

RECEIVED FROM University of Idaho
JML 74
Moscow, ID 83844-2060

SAMPLE OF Biodiesel Fuel (CEE)

LABORATORY NO 6 11 15 42

MARKED Yellowstone #7

Water & Sediment, %	Trace (<0.005)
Ramsbottom Carbon as received, %	0.00
Ash, %	0.000
Sulfur, %	<0.005
Carbon, %	78.08
Hydrogen, %	12.08
Oxygen %, by difference	9.84
Nitrogen, ppm	40
Cetane Rating	53.9
Iodine No.	117.3
Particulate Matter, mg/L	
Total	12.48
Non-Combustible	3.36
Copper Corrosion, 3 hrs. @ 122°F	slight tarnish, 1A
Phosphorus, %	0.002

Distillation

	Temperature, °F
Initial Boiling Point	240
2%	512
	Distillation discontinue due to decomposition

Arthur A. Krawetz

DIVERSIFIED LABORATORIES, INC.

3810 CONCORDE PARKWAY • CHANTILLY, VIRGINIA 22021 • (703) 222-8700

Certificate of Analysis

Submitted by: UNIVERSITY OF IDAHO

Sample: DP# 128463 BIODIESEL FUEL REE YELLOWSTONE LOT 1 3-31-95

Date received: 4-10-95

Analyses requested: TOTAL GLYCERINE, FREE GLYCERINE, MONOGLYCERIDES, DIGLYCERIDES, TRIGLYCERIDES, FREE FATTY ACIDS, ETHYL ESTER CONTENT

TOTAL GLYCERINE:	2.03%
FREE GLYCERINE:	1.21%
MONOGLYCERIDES:	LESS THAN 0.50%
DIGLYCERIDES:	1.66%
TRIGLYCERIDES:	1.33%
FREE FATTY ACIDS:	0%
ETHYL ESTER CONTENT:	96.83%

Date FAXED: 9-12-95

Control Number 02586

Authorized Signature Ph.D.

"Service Through Science"

DIVERSIFIED LABORATORIES, INC.

3810 CONCORDE PARKWAY • CHANTILLY, VIRGINIA 22021 • (703) 222-8700

Certificate of Analysis

Submitted by: UNIVERSITY OF IDAHO

Sample: DP# 128530 REE YELLOWSTONE LOT 2 5-31-95

Date received: 6-09-95

Analyses requested: TOTAL GLYCERINE, FREE GLYCERINE, MONOGLYCERIDES, DIGLYCERIDES, TRIGLYCERIDES, FREE FATTY ACIDS, ETHYL ESTER CONTENT

TOTAL GLYCERINE:	0.39%
FREE GLYCERINE:	0.14%
MONOGLYCERIDES:	0.22%
DIGLYCERIDES:	1.95%
TRIGLYCERIDES:	0.46%
FREE FATTY ACIDS:	0.64%
ETHYL ESTER CONTENT:	96.53%

Date FAXED: 9-07-95

Control Number 04664

Authorized Signature Ph.D.

"Service Through Science"

DIVERSIFIED LABORATORIES, INC.

3810 CONCORDE PARKWAY • CHANTILLY, VIRGINIA 22021 • (703) 222-8700

Certificate of Analysis

Submitted by: UNIVERSITY OF IDAHO

Sample: DP# 134444 BIODIESEL FUEL OF RAPESEED ETHYL 7-18-95 #3

Date received: 8-01-95

Analyses requested: TOTAL GLYCERINE, FREE GLYCERINE, MONOGLYCERIDES, DIGLYCERIDES, TRIGLYCERIDES, FREE FATTY ACIDS, ETHYL ESTER CONTENT

TOTAL GLYCERINE:	0.31%
FREE GLYCERINE:	0.13%
MONOGLYCERIDES:	LESS THAN 0.5%
DIGLYCERIDES:	3.37%
TRIGLYCERIDES:	1.79%
FREE FATTY ACIDS:	0.41%
ETHYL ESTER CONTENT:	94.11%

Date FAXED: 9-12-95

Control Number 06440

Authorized Signature Ph.D.

"Service Through Science"

DIVERSIFIED LABORATORIES, INC.
3810 CONCORDE PARKWAY • CHANTILLY, VIRGINIA 22021 • (703) 222-8700

Certificate of Analysis

Submitted by: UNIVERSITY OF IDAHO
Sample: YELLOWSTONE #4 PO# 143641 9-15-95
Date received: 9-26-95
Analyses requested: TOTAL GLYCERINE, FREE GLYCERINE, MONOGLYCERIDES, DIGLYCERIDES, TRIGLYCERIDES, FREE FATTY ACIDS

FREE FATTY ACIDS:	0.42%
FREE GLYCERINE:	0.20%
MONOGLYCERIDES:	TRACE
DIGLYCERIDES:	4.63%
TRIGLYCERIDES:	2.70%
ESTERS:	91.87%
TOTAL:	99.82%
TOTAL GLYCERINE:	4.09%

Date FAXED: 1-24-96

Control Number 08464

Authorized Signature Ph.D.

"Service Through Science"

DIVERSIFIED LABORATORIES, INC.

3810 CONCORDE PARKWAY • CHANTILLY, VIRGINIA 22021 • (703) 222-8700

Certificate of Analysis

Submitted by: UNIVERSITY OF IDAHO

Sample: DP# 139691 BIODISEL FUEL OF RAPESEED ETHYL ESTER (REE)

Date received: 8-25-95

Analyses requested: TOTAL GLYCERINE, FREE GLYCERINE, MONOGLYCERIDES, DIGLYCERIDES, TRIGLYCERIDES, FREE FATTY ACIDS, ETHYL ESTER CONTENT

TOTAL GLYCERINE:	0.54%
FREE GLYCERINE:	0.02%
MONOGLYCERIDES:	2.97%
DIGLYCERIDES:	3.40%
TRIGLYCERIDES:	2.21%
FREE FATTY ACIDS:	0.42%
ETHYL ESTER CONTENT:	90.43%

CONTINUATION OF SAMPLE DESCRIPTION: YELLOWSTONE #5 8-04-95

Date FAXED: 9-07-95

Control Number 07353

Roger Garrett Ph.D.

Authorized Signature

"Service Through Science"

DIVERSIFIED LABORATORIES, INC.
3610 CONCORDE PARKWAY • CHANTILLY, VIRGINIA 20151 • (703) 222-9700

Certificate of Analysis

Submitted by: UNIVERSITY OF IDAHO

Sample: BIODIESEL FUEL SAMPLE OF CANOLA ETHYL ESTER (CEE) POS

Date received: 6-07-96 Lot 6

Analyses requested: TOTAL GLYCERINE, FREE GLYCERINE, MONOGLYCERIDES, DIGLYCERIDES, TRIGLYCERIDES, FREE FATTY ACIDS, PERCENT ESTER

FREE FATTY ACIDS:	0.78%
FREE GLYCERINE:	0.21%
MONOGLYCERIDES:	TRACE
DIGLYCERIDES:	4.42%
TRIGLYCERIDES:	1.60%
ESTERS:	92.88%
TOTAL:	99.89%
TOTAL GLYCERINE:	6.78%

CONTINUATION OF SAMPLE DESCRIPTION: 159422

Date FAXED: 11-11-96

Control Number 17474

Authorized Signature Ph.D.

"Service Through Science"

Appendix C

Truck fuel and driving log

YELLOWSTONE NATIONAL PARK BIODIESEL LOG 9/1/98

1998	MILEAGE		FUEL			ROAD SURFACE PAVED		OUTSIDE AIR TEMP		OIL	MAINTENANCE
DATE	START	END	GAL	AUX TANK	MPG	YES	NO	A.M.	P.M.	QTS	WORK DONE
3/24/98	79370	79637	19.5	5529.9	13.7	X		31	46		Put 150 gallons in Slip tank
3/30/98	79637	79976	25.7	5555.6	13.2	X		32			Trip to Casper
3/30/98	79976	80245	20.6	5578.1	13.1	X			34		Trip to Casper
3/30/98	80245	80602	33.9	5612.7	10.5	X		38			Trip to Casper
4/2/98	80602	80954	29.5	5646.8	11.9	X			71		Trip to Casper
4/3/98	80954	81143	17	5663.8	11.1	X		33	63		Trip to Casper
4/6/98	81143	81528	26.3	5690.1	14.6	X		25			Trip to Casper
4/15/98	81528	81857	26.6	5716.7	12.7	X					Mammoth to Diversion Lake, WY
4/15/98	81857	81938				X			38		To Fort Colllins, CO
4/16/98	81938	81988				X			55		AR Denver
4/17/98	81988	82005				X		25			LV Denver AR Longmont
4/19/98	82005	82084				X			60		LV Longmont AR Rocky Mtn NP
4/20/98	82084	82104				X		25	55		LV Rocky Mtn NP AR Lakewood
4/21/98	82104	82121	19.1	57358	13.8	X		25	55		Regional Office
4/21/98	82121	82142				X		30	60		Regional Office
4/22/98	82142	82151				X		35	70		Regional Office
4/23/98	82151	82567	27.4	5763.3	16.2	X	X	40	80		LV Denver AR Shoshone, WY
4/23/98	82567	82804				X					LV Shoshone AR Mammoth
4/26/98	82804	83121				X					Service
4/30/98	83121	83499	22.3	5798.7	16.9	X		41	71		Filled Aux tank for AZ Trip
5/4/98	83499	83770	23.8	5822.6	11.4	X		50			Fueled - Bountiful, UT
5/4/98	83770	84022	22.6	5845.2	11.2	X		60			Fueled - Bear Valley, UT
5/7/98	84022	84360	16.7	5861.9	20.2	X		70	70		Fueled - Kanab, UT
5/8/98	84360	84732	22.9	5884.9	16.2	X		65			Fueled - Centerville, UT
5/11/98	84732	85093	24.6		14.7	X					SERVICE/Filled Aux tank
5/15/98	85093	85354	26.7	5911.5	10	X		60			Fueled - Missoula, MT
5/16/98	85354	85717	14.3	5925.9	25.3	X		60			Fueled - Moscow, ID
5/17/98	85717	86137	27.3	5953.3	15.4	X		60			Fueled - Jorden Valley, OR
5/18/98	86137	86277	13	5966.3	10.8	X		50			Fueled - Sacramento, CA
5/18/98	86277	86887	23.7	5990	25.7	X		65			Fueled - Changed tank filter
5/29/98	86887	87225	27.6	6017	12.2	X		60			Fueled - Laynta Test - Dyno
5/30/98	87225	87463	21.7	6039.3	11	X		70			Fueled - Bakersfield, CA
5/30/98	87463	87840	21	6060.4	18	X		60			Fueled - Truckee, CA

1998	MILEAGE		FUEL			ROAD SURFACE PAVED		OUTSIDE AIR TEMP		OIL	MAINTENANCE
DATE	START	END	GAL	AUX TANK	MPG	YES	NO	A.M.	P.M.	QTS	WORK DONE
5/31/98	87840	88287	24.5	6085	18.2	X		60			Fueled - Jorden Valley, OR
6/3/98	88287	88374	8.3	6093.3	10.5	X		60			Fueled - Spokane, Aux tank pump stopped
6/4/98	88374	88605	13	6106.4	17.7	X		65			Fueled - Moscow, ID - Replaced Aux filter
6/5/98	88605	88953	24.5	6131	14.2	X		65			Fueled - Moscow, ID
6/5/98	88953	89165	25.4	6156.4	8.3	X		60			Fueled - Deer Lodge, MT
6/8/98	89165	89540	15.8	6172.3	23.7	X		60			Fueled - LV Mammoth for MI
6/8/98	89540	89768	28.3	6200.6	8.1	X		55			Terry, MT
6/9/98	89768	90207	24.2	6224.8	18.1	X		51			Bismark, ND
6/9/98	90207	90517	21.5	6246.3	14.4	X		60			LV Bismark, ND AR Jamestown, MI
6/9/98	90517	90749	20.8	6267.3	11.2	X		60			Bellair, MI
6/10/98	90749	90841				X		60			local driving
6/12/98	90841	91216	22.5	6289.7	16.6	X					Fueled - Shanty Creek Bellaire, MI
6/13/98	91216	91549	23.5	6313	14.2	X					MI
6/14/98	91549	91917	24	6337.1	15.3	X					Roadside rest area - MN
6/14/98	91917	92017				X					Dickinson, SD
6/15/98	92017	92244	26.6	6363.7	12.3	X					Fueled - Billings, MT
6/15/98	92244	92450	26.2	6390	7.98	X					
6/23/98	92450	92554	19.7	6409.7	5.3	X					Mammoth - Old Faithful, Fueled/Mammoth

YELLOWSTONE NATIONAL PARK BIODIESEL LOG 3/26/98

1998	MILEAGE		FUEL			ROAD SURFACE PAVED		OUTSIDE AIR TEMP		OIL	MAINTENANCE
DATE	START	END	GAL.	AUX TANK	MPG	YES	NO	A.M.	P.M.	QTS	WORK DONE
10/14/97	73256	73658									Travel around Mammoth
10/14/97	73658	73660	25.9	5109.5	15.6	X		28	46	OK	Heated slip tank to dispense
10/15/97	73660	73820									
10/16/97	73820	73987									
10/21/97	73987	73988									Dispensed 150 gallons into slip tank
10/21/97	73988										Left for Billings
10/25/97		74368				X		20s	40s		Return from Billings
10/28/97	74368	74381	27.2	5136.8	14.4	X		21	43	OK	Fueled up - Mammoth
11/6/97	74381	74794	27.6	5164.4	14.9	X		19	50	OK	Jackson, WY and return
11/10/97	74821										SERVICE
11/12/97	74821	75195	10.1	5174.5	Partial fill	X		9	35	OK	To Boulder, MT
11/12/97	75195	75280	27	5201.5	12.4	X		9	35	OK	Bozeman, MT - Complete fill
11/15/97	75280	75545	19.1	5220.6	13.9	X		2	36	OK	Butte, MT
11/16/97	75545	75806	25.1	5245.7	10.4	X		3	40	OK	Pocatello, ID
11/16/97	75806	75978	11	5256.7	15.6	X		40	40	OK	Salt Lake City, UT
11/22/97	75978	76262	21	5277.7	13.5	X		28	34	OK	Ashton, ID
12/2/97	76262	76487	17.8	5295.5	12.6	X		26	32	OK	Return from Bozeman
1/26/98	76487	76718				X		0	19	OK	Travel around Yellowstone
2/2/98	76718	76769	24.9	5320.4	11.3	X		5	10	OK	Mammoth to Grant Teton NP
2/4/98	76769	77183	31	5351.4	13.4	X		20	32	OK	Jackson, Wy to Mammoth
2/14/98	77183	77490	19.2	5370.6	16	X		20	35	OK	To Belgrade, MT and return
2/16/98	77490	77910	26.8	5397.4	15.7	X		30	45		To Belgrade, MT and return
2/18/98	77910	78321	30.1	5427.5	13.7	X		34	42		To Casper, WY and return
2/18/98	78321	78718	28.5	5456	13.9	X		45	45		To Columbus, MT
2/18/98	78718	78859	10.2	5466.2	13.8	X		45	40	OK	Columbus, MT to Mammoth
2/24/98	78865										SERVICE - slip filter and fuel line
3/9/98	78865	79154	26.9	5493.1	10.7	X		15	35		To Red Lodge, MT
3/15/98	79154	79370	17.6	5510.7	12.3	X		30	45		Red Lodge to Mammoth

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1997	MILEAGE		FUEL			ROAD SURFACE PAVED?		OUTSIDE AIR TEMP		OIL	MAINTENANCE
DATE	START	END	GAL	AUX TANK	MPG	YES	NO	A.M	P.M	QTS	WORK DONE
8/20		66302	22.4	4602.5		X		47	78		Fueled in Mammoth
8/24	66302	66574	20.1	4623.3	13.5	X		60			Fueled @ Rest area (by Missoula)
8/23						X					Filled Auxillary Tank
8/24	66574	66955	27.3	4650.6	13.9	X			70+		Filled@Scenic ovrlk/Columbia River
8/30	66955	67235	21.7	4672.3	12.9	X		70			Filled @ Roslyn Exit, WA/slow pump
8/30	67235	67536	16.4	4688.8	18.3	X			60		Fueled @ Missoula/pump very slow
8/30	67536	67637	5.0	4693.8	20.2	X			60		Tried to fill again/bad pump
9/3	67637	67935	18.8	4717.2	15.6	X		56	79		Changed sliptank filter/truck fltr
9/5	67935	68074	8.6	4725.9	16.2	X					Serviced
9/7	68074	68452	23.0	4748.9	16.4	X		41	80		Wamsutter, WY
9/9	68452	68845	23.5	4772.4	16.7	X		40	75		Arvada, CO
9/10	68845	69064	14.0	4786.5	15.6	X		45	70		Steamboat Springs, CO
9/11	69064	69387	22.5	4809	14.3	X		44	70		Pinedale, WY
9/12	69387	69621	17.7	4826.7	13.2	X		44	60		Mammoth, YNP
9/15	69621	69975	25.5	4853.3	13.9	X		45	70		Cheyenne, WY
9/16	69975	70318	32.8	4886.1	10.5	X		40	60		Casper, WY
9/17	70318	70706	25.8	4911.9	15.1	X		50	60		To Mammoth/Serviced
9/18	70706	71061	23.9	4935.8	14.8	X			65		Clearfield, UT
9/19	71061	71431	24.0	4959.8	15.4	X			65		McGiu, NV
9/20	71431	71752	24.6	4984.4	13.1	X			70		Leevining, CA
9/22						X					Yosemite/Hodgoon Mdw, Sacramento
9/25	71752	72195	29.8	5014.2	14.9	X			60		Stockton, to Hardin Flat, CA
9/26	72195	72552	23.8	5038.0	15.0	X			80		Middines, Ca/Warm Sprins, NV
9/27	72552	72945	26.0	5064.0	15.1	X			65		Wells, NV
9/30	72945	73256	19.6	5083.6	15.9	X			65		Mammoth, WY

1997	MILEAGE		FUEL			ROAD SURFACE PAVED?		OUTSIDE AIR TEMP		OIL	MAINTENANCE
DATE	START	END	GAL	AUX TANK	MPG	YES	NO	A.M	P.M	QTS	WORK DONE
4/28	57693	58146	30.2		15.0	X		36	56		Fueled at Norris
5/1	58497										Service/filled aux. tank - 175
5/4		58500	20.8	3999.8	17.0						Filled aux. tank
5/4	58500	58940	27.6	4027.4	15.9	X		40	56		Fueled/Mammoth - Jensen
5/4	58940	59311	25.0	4052.4	14.8	X		38	65		Fueled in Rawlins
5/6	59311	59612	25.2	4077.6	12.0	X		45	70		Fueled in Casper, WY
5/7	59612	60015	27.0	4104.6	14.9	X		50	75		Fueled in Cody, WY
5/14	60015	60327	24	4128.6	13.0	X		55	80		Fueled in Helena, MT
5/20	60327	60700	24.8	4153.4	15.0	X		40	65		Fueled in Yellowstone
5/26	60700	61124	25.9	4179.3	16.4	X		35	45		Fueled @ Northeast Entr, YNP
5/29	61124	61372	16.8	4196.1	14.7	X		38	70		Fueled in East Glacier, GLAC
6/5	61372	61763	27.3	4223.4	14.3	X		45	70		Fueled in Nine Mile/Missoula
6/9	61763										Service
6/13	61763	62097	19	4242.4	17.6	X		40	68		Fueled in Yellowstone
6/16	62097	62303	12.3	4254.7	16.7	X		45	75		Fueled at Island Park
6/17	62303	62729	28.4	4283.1	15.0	X		50	80		Fueled in Yellowstone
7/8	63452										Had to put slip tank fuel back in truck/minus 110 gal./mistake by garage personnel.
7/10	63452	63871	27.8	4426.2	15.1	X		55	82		Fueled in Boise, Id
7/14	63871	64239	24.5	4451.2	15.0	X		60	89		?
7/15	64239	64589	23.1	4474.3	15.1						?
7/17	64589	64843	23.0	4497.5	11.0						Service
7/29	64843	65095	29.8	4527.3	8.5	X		45	70		Filled @ Craters of the Moon
7/30	65095	65521	26.8	4554.1	15.9	X	X	63	82		Fueled in West Yellowstone
8/4	65521	65971	25.9	4580.0	17.4	X		65	75		Fueled in Yellowstone

1994	MILEAGE		FUEL			ROAD SURFACE PAVED?		OUTSIDE AIR TEMP		OIL	MAINTENANCE
DATE	START	END	GAL	AUX TANK	MPG	YES	NO	A.M	P.M	QTS	WORK DONE
3/17	52296					X		35			Left to Denver
3/17		52604	20.7		14.9	X			40		Filled in Sheridan, WY
3/17	52604	52937	27.0		12.3	X			46		Filled in Cheyenne, WY
3/18	52937	53196	20.1		12.9	X		32	60		Arrive in Denver
3/20	53196	53551	28.0		12.7	X		45	60		Filled in Cheyenne
3/21	53551	53834	21.4		13.2	X		35			Back to Yellowstone
3/24	53834	54233	29.6		13.5	X					Yellowstone to Denver
3/24	54233	54488	20.2		12.6	X					Arrive Denver
3/27	54488	54839	26.9	3776.4	13.0	X		45	60		Depart Denver
3/27	54839	55199	28.9	3805.3	12.4	X					Arrive Tetons - Fill up
3/29	55199	55371	12.2	3817.5	14.1	X		25	45		Arrive Mammoth
3/31	55378										Service
4/7	55371	55824	29.0	3846.5	15.6	X		15	50		Brigham City, UT
4/10	55824	56132	23.8	3870.3	12.9	X		20	45		Rexburg, ID
4/17	56132	56499	22.5		16.3	X		33			To Grand Junction, CO
4/21	56499	56904	24.2	3894.5	16.7	X		45	63		Filled @ Salt Lake City, UT
4/23	56904	57344	30.3	3924.9	14.5	X		65	75		Filled @ Moab, UT
4/25	57344	57693	23.6	3948.7	14.8	X		40	70		Filled @ Spanish Fork

1996	MILEAGE		FUEL			ROAD SURFACE PAVED?		OUTSIDE AIR TEMP		OIL	MAINTENANCE
DATE	START	END	GAL	AUX TANK	MPG	YES	NO	A.M	P.M	QTS	WORK DONE
12/16	49114										Crankcase level 1/8" above full
1/13	49248										Trip to Helena/Crankcase 1/4" above full.
1/13	49248	49341	16.9		13.4						Fueled up in Bozeman
1/13	49341					X		-21	-10		Cold weather/ran fine/oil level ok
1/14	49341	49564	17.2	3384.6	12.9	X		-20	+5		Oil level
1/21	49564	49828	20.9	3405.5	12.6	X			+30		Oil 1/8" above full
2/18	49828					X		+41	+56		To Billings MATE Show
2/22	49828	50012	12.1	3417.6	15.3	X		+18	+50		Billings to Yellowstone
2/22	50012	50242	16.0	3433.6	14.4	X		+6	+31		Yellowstone to Missoula
3/1	50242	50525	25.6	3459.2	11.1	X		+19	+39		Missoula
3/3	50525	50782									Arrive Spokane
3/4	50782										Injector Imaging, changed fuel filter.
3/5	50782	50928									Dyno testing in Spokane
3/5	50928	50939									Fuel line blew--replaced
3/5	50939	51053	30.0	3489.2	17.6	X					
3/6	51053	51437	27.4	3516.6	14.01	X		+20	+42		Fueled in Bozeman
3/9	51437							+25			Oil level 1/8" above full
3/9	51437	51847	28.2	3544.8	14.5	X			+35		Glacier NP, 4WD 1/2 the way
3/12	51847					X		+30			Glacier
3/12	51847	52208	28.5	3573.3	12.7	X			+30		Fueled in Bozeman - 150mi. 4WD
3/14	52208	52295									Service - change hoses

1996	MILEAGE		FUEL			ROAD SURFACE PAVED?		OUTSIDE AIR TEMP		OIL	MAINTENANCE
DATE	START	END	GAL	AUX TANK	MPG	YES	NO	A.M	P.M	QTS	WORK DONE
10/1	46001					X		36	55		Driving around Park
10/3	46051					X		40	66		Dispensed 160 gal. into aux tank
10/5	46062										Leave Mammoth for Jackson, WY
10/6		46565	29.2		19.32	X					Fueled at Arlington, WY
10/8	46765	46971	26.6		15.26	X					LV Denver, CO - AR Laramie, WY
10/9	46971	47376	26.6		15.23	X					LV Laramie
10/10		47512				X					AR Mammoth
10/22	47512	47698	21.5	3248.5	14.98						Fueled up
10/23	47698	47979	20.0	3268.5	14.05	X		20	50		To Bozeman
10/25	47979	48378	31.8	3330.3	12.55	X	X	25	30		To Livingston (from Red Lodge)
11/5	48378	48695	23.0		13.78						
11/5	48695										SERVICED
11/7	48695	48838	11.1	3334.4	12.88	X					Fueled - Yellowstone
11/13						X					Mammoth to Idaho Falls, ID
11/14	48838	49091	15.0	3348.8	16.87	X					Fueled - Idaho Falls to Mammoth
11/17	49091										Investigate rise in crankcase level
11/22											Crankcase level okay.
12/5		49114									Crankcase level okay.

1996	MILEAGE		FUEL			ROAD SURFACE PAVED?		OUTSIDE AIR TEMP		OIL	MAINTENANCE
DATE	START	END	GAL	AUX TANK	MPG	YES	NO	A.M	P.M	QTS	WORK DONE
9/3	40568	40796				X		46	77		Fueled in Yellowstone
9/11	40796	41131	28.7	2812.3	19.6	X		48			Fueled in Yellowstone
9/13	41131	41523	24.9	2840.6	15.7	X		50	80		To Hardin, MT/oil ok
9/13	41523	41888	25.5	2866.2	14.3	X					Guernsey, WY
9/14	41888	42137	18.4	2884.6	13.5	X		52	75		North Platte, NE/oil ok
9/14	42137	42509	25.5	2910.1	14.6	X					St. Joseph, MO/oil ok
9/14	42509	42932	28.1	2938.2	15.1	X					Benton, MO/oil ok
9/15	42932	43126	9.7	2948.0	20.0	X		52	80		Memphis, TN/oil ok
9/18	43126	43376	20.7	2968.7	12.1	X		73	63		Nashville, TN/oil ok
9/20	43376	43863	29.5	2998.2	16.5	X		68	74		Edgar Springs, MO/oil ok
9/21	43863	44287	31.2	3029.4	13.6	X		50			Unadilla, NE/oil ok
9/21	44287	44715	27.3	3056.8	15.7	X			74		Scottsbluff, NE/oil ok
9/22	44715	45120	32.1	3088.9	12.7	X		40	68		Cody, WY - Park radio not working
9/23	45120	45484	9	3098.0	19.2	X			55		Helena, MT
9/26	45484	45696	24.5	3122.5	14.6	X			40		Fueled in Mammoth
9/27	45696	45847				X			40		Travel to Jackson, WY
9/28	45847	46001	15.4	3138.0	19.8	X		30	50		Jackson back to Mammoth

1996	MILEAGE		FUEL			ROAD SURFACE PAVED?		OUTSIDE AIR TEMP		OIL	MAINTENANCE
DATE	START	END	GAL	AUX TANK	MPG	YES	NO	A.M	P.M	QTS	WORK DONE
7/6	37657	37660				X		62			Washed truck
7/10	37700	37872	13.1	2597.7	16.4	X		61	84		To INEL & Return/Solenoid valve failed - had to manually start
7/19	37872	38255	27.6	2625.4	13.9	X		46	69		Trip to Bozeman
8/9	38255	38989	23.4	2648.8	31.4	X		40			To Lander, WY
8/16				2672.3							SERVICE - Fill slip tank - Replace Hose
8/20	38989	39517	24.5	2696.8	21.5	X		58	80		To Crow Agency
8/20	39517	39760	29.5	2726.3	8.2	X		80	80		and Return
8/21	39760	40242	22.0	2748.3	21.9	X		50	80		To Butte and return
8/28	40242	40568	16	2764.3	20.4	X		51	84		Mammoth/Canyon/Mammoth

1996	MILEAGE		FUEL			ROAD SURFACE PAVED?		OUTSIDE AIR TEMP		OIL	MAINTENANCE
DATE	STAPT	END	GAL	AUX TANK	MPG	YES	NO	A.M	P.M	QTS	WORK DONE
6/20	35467	35485	16.3	2437.5	12.5	X		50	72		Fueled up
6/21	35485					X		45	73		Trip to Livingston
6/25		35646	9.4	2446.9	17.1	X		51	76		Fueled up
6/26	35646	36012	12.9	2459.8	28.3	X	X				Partial - Big Tank Dry
6/26	36012										SERVICED - Filled sliptank - 15gal
6/27	36012	36347	19.3	2494.4	17.4	X		54	81		Salt Lake City (fueled up @ Brigham City
6/28	36347	36420				X		60			Salt Lake City
6/29	36420	36666	24.5	2518.9	13.2	X	X				SLC to Beaver, UT (Pole Cr. Fire)
6/30	36666	36692					X		72		Pole Creek Fire
7/1	36692	36817					X	41			Pole Creek Fire
7/2	36817	36885				X	X	54			Pole Cr. Fire to Richfield, UT and return
7/2	36885	36940				X	X	51			Pole Cr. Fire to Richfield, UT and return
7/3	36940	37005	19.1	2518	17.7	X	X				Flat tire - washed truck swap spare tire for R/F - coming apart
7/3	37005	37031				X	X				Pole Creek Fire to Cove Fort Fire
7/4	37031	37060				X	X				Refueled on Cove Fort Fire
7/4	37060	37107				X	X				Flat tire
7/5	37107	37324				X					Cove Fort fire to Richfield
7/5	37324	37657	26.8	2564.8	24.3	X		56			Richfield to Mammoth

1996	MILEAGE		FUEL			ROAD SURFACE PAVED?		OUTSIDE AIR TEMP		OIL	MAINTENANCE	
DATE	START	END	GAL	AUX TANK	MPG	YES	NO	A.M	P.M	QTS	WORK DONE	DRIVER
4/9	30245	30561	25.2	2105.4	12.5	X		32	70		Drive around the Park.	Evanoff
4/14	30561	30997	28	2133.4	15.6	X		32	60		Mammoth to Salt Lake City, UT	Roberts
4/17	30997	31324	26.9	2160.3	12.2						Salt Lake to Mammoth	
4/17	31324	31378										
5/1	31378	31752	30	2190.3	14.3	X		26	43		Drive around the Park. Fill-up	Evanoff
5/3	31752	32062	17.3	2207.7	17.9	X		40	62		To Laurel for presentation.	Evanoff
5/7	32062	32448	26.7	2234.4	14.5	X		39	57		Fueled up	Evanoff
5/14	32448	32845				X					Mammoth to Salt Lake	Roberts
5/15	32845	32954	33	2267.5	15.33	X					Salt Lake to Idaho Falls	Roberts
5/16	32954	33260									Idaho Falls to Mammoth	Roberts
5/22	33260	33282	24.3	2291.9	13.5	X		45	65		Fueled up	Evanoff
6/4	33282	33502									Serviced	
6/6	33502	33756	28	2319.9	16.9	X		70			Partial fill - Bozeman	Hudson
6/6	33756	33842				X		70			Partial fill - Boulder, MT	Hudson
6/6	33842	33886				X		70			Partial fill - Butte, MT	Hudson
6/6	33886	33997				X		60			Partial fill - Livingston, MT	Hudson
6/7	33997	34072	20.5	2340.4	15.4	X		80				Perkins
6/7	34072	34432	25.8	2366.2	13.9							
6/10	34432	34668	17.9	2384.1	13.2	X		75			Partial fill - Helena	Edwards
	34668	34867	18.9	2403.0	10.5	X		70	85		Partial fill - Helena to Mammoth	Edwards
	34867	35182				X	X				Mammoth to Red Lodge, MT / return	Hudson
	35182	35282	24.2	2427.2	17.1	X		72	72		West Yellowstone / return	
6/17	35282	35288				X		56	74		Local travel - Mammoth	Bahr
6/18	35288	35292				X		48	62		Local travel - Mammoth	Bahr
6/19	35292	35467				X		32	66		Mammoth to Bozeman / return	Bahr

1996	MILEAGE		FUEL			ROAD SURFACE PAVED?		OUTSIDE AIR TEMP		OIL	MAINTENANCE	DRIVER
DATE	START	END	GAL	MPG	AUX TANK	YES	NO	A.M	P.M	QTS	WORK DONE	
1/30		26294				X		-15	0		Travel around park	Evanoff
2/1	26294	26322				X		-31	-15		Working well in cold weather	Evanoff
2/4	26322	26350				X		-33	-19		Plugged in - WILL NOT START	Evanoff
2/6	26350	26363				X		-3	+18		Running fine - NO PROBLEMS	Evanoff
2/10	26363	26410				X		-5	+13		Forgot to plug in for 2 days - still started	Evanoff
2/13	26410	26582				X		+19	+45		Drove to Billings for Ag Show (MATE)	Evanoff
2/14-17											Ag Show at Billings	
2/17	26410	26582	23.5	12.3	1840.5	X		+75	+75		Fueled up at Ag Show	Evanoff
2/26	26582	26808	18.1	12.5	1859.3	X		0	+5		Fueled up at Mammoth	Evanoff
2/27	26808	27002				X		-15	0		Helena, MT - 50-70 MPH	Mack
2/28	27002	27202	23.0	17.1	1882.4	X		-15	-6		Plugged in -started fine @-15 fueled up in Mammoth	Mack
2/29	27202	27338	14.1	9.6	1896.6	X		-5	+10		Plugged in - started fine	Mack
3/1	27338	27342				X		+16	+41			Mack
3/3	27342	27989	45.8	14.2	1916.6 1942.4	X		+26	+40		Plugged in - started fine heated fuel & pumped ok	Mack
3/4	27989	28324				X		+32	+36		Cheyenne, WY - not plugged in but started fine	Mack
3/5	28324	28641	45.8	14.2	1972.4 1988.3	X		+10	+24		Traveled from Sheridan to Mammoth, plugged in - started	Mack
3/11	28641	29069	29	14.8	2017.3	X		+44	+53		To Wallace Idaho & Vancouver, WA	Reinhart
3/?	29069	29525	20.7	22.0		X					Moscow, ID - Dyno test, performance test (changed oil and fuel filter)	Reinhart
3/14	29525	29975	29	15.5	2040.8 2069.7	X		+43	+56		Belgrade, MT to Mammoth - returning from Vancouver, WA	Reinhart
3/31	29975	30102				X					Travel around the park	Evanoff

1995	MILEAGE		FUEL			ROAD SURFACE PAVED?		OUTSIDE AIR TEMP		OIL	MAINTENANCE
DATE	START	END	GAL	AUX TANK	MPG	YES	NO	A.M	P.M	QTS	WORK DONE
7/11	14396	14636	5.8	747.7		X		65	85		Oil sample sent in -low viscosity
7/18	14636	14911	20.4	768.1	11.7	X		55	75		Fueled up - driving in Park
7/26	14911	15239	14.3	782.7	19.23	X		70	81		Fueled up - driving in Park
7/28	15239	15570	21.7	804.4	15.12	X		65	90		To Missoula - back to Park
8/01	15570	15823	21.4	825.9	15.47	X		60	80		Returned to Mammoth Fueled up
8/07	15823	15921				X		70	85		Dyno Test in Billings
8/07	15921	16330	16.1	862.7	21.8						Test in Billings T & E Truck was stationary
8/16	16330	16340	25.3	888.0	16.17	X		66	83		Fueled Up
8/17	16340	16340									Service
8/22	16340	17280	29.2			X		82			Wells, Nevada, traveling to Alpine Meadows, CA
8/23	17280	17778	28.5	945.5	16.46	X		50	65		Truckee, California
8/24	17778	18108	27.1	972.5	18.38			60			Twin Falls, Idaho
		18108									Arrive Mammoth
8/28	18218	18496	25.1	997.8	17.53	X		60	85		Travel to Bozeman
9/11	18496	18827	18.5	1015.	15.03	X		50	85		Fueled up on way to Cody
9/15	18827	19155	21.0	1036.	15.76	X		50	80		Jackson, WY and back
9/21	19155	19301	16.0	1052.	20.50	X		24	50		Trips within Yellowstone
9/26	19301	19773	14.4	1067.1	10.14	X		30	60		Install heater exchanges in tank
10/02	19773	19773	29.8	1097.	15.84	X		21	45		Filled truck tank

1995	MILEAGE		FUEL			ROAD SURFACE PAVED?		OUTSIDE AIR TEMP		OIL	MAINTENANCE
DATE	START	END	GAL	AUX TANK	MPG	YES	NO	A.M	P.M	QTS	WORK DONE
5/01	7551	7976	23.1	349.3	18	X		55	68	1	Fill up in Salt Lake
5/04	7976	8407	25.8	375.2	16.2	X		48	68		Fill up in Rexburg
5/05	8407	8538	7.3	382.5	17.8	X		45	60		Top off at Mammoth
5/05	8538										Service
5/07	8538	8984	19.8	402.3	22.6	X		32	50		Trip - Vernal, Utah
5/08	8984	9405	29.8	432.1	14.1	X		39	58		Cove Fort, Utah
5/13	9405	9885	28.7	460.8	16.7	X		60	50		Williams, Arizona
5/14	9885	10317	22.1	482.9	19.5	X		40	50		Canyon De Chelly, New Mexico and Arizona
5/15	10317	10824	27.2	510.1	18.6	X		50	50		Willard, Utah
5/16	10824	11147	15.9	526		X		45	60		Returned to Mammoth
5/17	11147	11320	14	540		X		60	40		Filled up Shop Tank
				540	to	569					No Fuel dispensed - sucked air
5/31	11320	11780	27	596		X					Drove to Arco, Idaho
6/02	11780	12005	14	610		X		65			Filled up - Gone to Missoula
6/05	12005	12490	26	636	18.7	X		50			Filled up - Return from Missoula
6/13	12490	12840									Service

6/13	12840	12840	22.5		15.6						
6/14	12840	13280						65	85		Drove to Arco Idaho and Returned
6/15	13280	13280	23.1	658							Fuel Up
6/18	13568	13944	18	699.7		X		45			Fuel Up - Trip to Cody
6/28	13944	14295	23	722.9			X	150			Fuel Up - Return trip from Bighorn
6/29	14295		17.2					50			Fuel Up - Return from Bozeman

1995	MILEAGE		FUEL			ROAD SURFACE PAVED?		OUTSIDE AIR TEMP		OIL		MAINTENANCE		TCM
DATE	START	END	GAL	AUX TANK	MPG	YES	NO	A.M	P.M	QTS	COST	WORK DONE	COST	
2/15	1906	2301	20			X		10	26	1				
2/16	2305	2309				X		14	23					
2/17	2313	2316								12		SERVICED - DUE AGAIN AT 6313		
2/21	2316	2854	15.9			X		32	50					
3/9	2854	3183	FULL			X						DYNAMOMETER TESTED SWITCHED OVER TO 100% R.E.E.		
3/13	3183	3364	12		15	X						INSTALLED TOPPER		
3/18		3776	24.4		16.4	X						BURNS JET.		
3/19		4246	27			X						BISHOP		
3/20		4583	17.3			X						LA - MTA		
3/24		5149	22			X			62			LA - MTA - N. LAS VEGAS -DINO TEST DONE		
3/25		5523	26		15	X			58			N. LAS VEGAS - SPANISH FORK		
3/25		5741	16		14	X		36	35			SPANISH FORK - POCATELLO		
3/26		5978	18		14	X		22	14			POCATELLO IDAHO - GARAGE		
3/28		5978								12		SERVICED - 5978		
4/2	5978	6320	20.3	245	14	X		24	46			DROVE TO MISSOULA		
4/5	6320	6402	9.6	254.6	16.8	X	3MI	24	59			MISSOULA - HELENA		
4/6	6482	6857	27.7	282.3	13.5	X	1MI	33	63			HELENA - TO CODY - TO EAST ENTRANCE		
4/10	7184	7197	1	283.5		X		19	27			NO FUEL WILL DISPENSE (CLOUDY)		
4/11		7214	9.1	292.6		X		26	45			DROVE AROUND PARK - DISPENSED		
4/17	7214	7354	20.5	313.1		X		25	40			TOPPED OFF TANK - SLOW GELLING SLOW - CLOUDY		
4/25	7551	7551	13	326.2		X		31	37			FUEL-UP FOR TRIP (FILLED SLIP TANK)		

Appendix D

LubeWatch Oil Analysis Reports

Chevron LubeWatch™
Maintenance Management System

(800) LUBE-808

Chevron Lubricants

11607 EAST TRENT AVENUE, SPOKANE, WASHINGTON 99206, (509) 921-9909, FAX (509) 921-9910

DESCRIPTION: NEW OIL SAMPLE

CUSTOMER NO.: 2000336 | UNIT NO.: YELLOWSTONE | OIL BRAND: ?

Condition: NORMAL | MAKE: | MODEL: | OIL TYPE: ?

Analyst : RGT | UNIT SERIAL NO.: | FUEL TYPE: | NO. COPIES: 2

NEW OIL

SAMPLE DATA

LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MAGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDEUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C	VIS 100° C	WATER % Vol	SOLIDS % Vol	GLYCOL
14537	06/28/95 ?		0	0	0	0	0	0	0	0	0	4	155	0	33	2448	2	977	1150	1	0	0	0	N/A	<1	N/A	14.95	0	N/A	NEG
	07/03/95 ?																													

ADDITIONAL CUSTOMER TESTS

LAB#	F-SOOT	TBN	SAE
14537	N/A	8.3	40

PARTICLE COUNT RESULTS

ANALYSIS RECOMMENDATIONS

LAB#	ANALYSIS RECOMMENDATIONS
14537	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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MAMMOTH HOT SPRINGS, WY 82190

CTC CV-100 3/95

Chevron LubeWatch
Maintenance Management System

(800) LUBE-808

Chevron Lubricants

CUSTOMER NO 19562 UNIT NO PARK
Condition: ABNORMAL
Analyst : RGT

DESCRIPTION ENGINE
MAKE DODGE MODEL 2500
UNIT SERIAL NO

OIL BRAND CHEVRON NUMBER COPIES 1
OIL TYPE DELO 15W40 TYPE SERVICE
FUEL TYPE DIESEL

SAMPLE DATA			SPECTROCHEMICAL ANALYSIS																						
LAB#	DATE TAKEN/ RECEIVED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM
✓ 3844	02/17/95	2313	35	1	6	25	0	3	0	0	0	25	201	7	748	838	94	1208	1477	1	0	0	0
	02/24/95	2313										****											

PHYSICAL PROPERTY DATA							
FLASH	FUEL % Vol	VIS 40°C cSt	VIS 100°C cSt	WATER %Vol	SOLIDS %Vol	GLYCOL
N/A	<1	N/A	12.58	0	0.1	NEG

LAB#	ADDITIONAL CUSTOMER TESTS										
	F-SOOT	TBN	SAE								
3844	0.1	7.7	40								

PARTICLE COUNT RESULTS

LAB#	ANALYSIS RECOMMENDATIONS

LAB#	ANALYSIS RECOMMENDATIONS
3844	SILICON LEVEL IS HIGH - POSSIBLY FROM NORMAL ENGINE BREAK-IN. RECOMMEND CHANGE LUBE OIL AND LUBE OIL FILTER, IF NOT ALREADY DONE. RECOMMEND RESAMPLE AT NORMAL INTERVAL.

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11607 EAST TRENT AVENUE, SPOKANE, WASHINGTON 99206, (509) 921-9909, FAX (509) 921-9910

DESCRIPTION: ENGINE

CUSTOMER NO.: 19562 UNIT NO.: PARK

OIL BRAND: CHEVRON

Condition: NORMAL

MAKE: DODGE MODEL: 2500 OIL TYPE: DELO 15W40

Analyst : RGT

UNIT SERIAL NO.: FUEL TYPE: DIESEL NO. COPIES: 2

SAMPLE DATA																														
LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MAGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDEUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C	VIS 120° C	WATER % Vol	SOLIDS % Vol	GLYCOL
✓3844	02/17/95	2313	35	1	6	25	0	3	0	0	0	25	201	7	748	838	94	1208	1477	1	0	0	0	N/A	<1	N/A	12.58	0	0.1	NEG
	02/24/95	2313										^^^^																		
✓8425	03/28/95	3662	20	1	3	24	0	4	0	0	0	10	140	1	97	2161	17	983	1127	0	0	0	0	N/A	<1	N/A	12.65	0	N/A	NEG
	04/24/95	5978																												

LAB#	ADDITIONAL CUSTOMER TESTS											PARTICLE COUNT RESULTS
	F-SOOT	TBN	SAE									
3844	0.1	7.7	40									
8425	0.1	5.3	40									

LAB#	ANALYSIS RECOMMENDATIONS

LAB#	ANALYSIS RECOMMENDATIONS
3844	SILICON LEVEL IS HIGH - POSSIBLY FROM NORMAL ENGINE BREAK-IN. RECOMMEND CHANGE LUBE OIL AND LUBE OIL FILTER, IF NOT ALREADY DONE. RECOMMEND RESAMPLE AT NORMAL INTERVAL.
8425	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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Chevron LubeWatch
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11607 EAST TRENT AVENUE, SPOKANE, WASHINGTON 99206, (509) 921-9909, FAX (509) 921-9910

DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: 231543-YELLOW

Condition: ABNORMAL

Analyst : RGT

MAKE: DODGE MODEL: B-250 5.9

UNIT SERIAL NO.: 1B7KF26C85233913

OIL BRAND: CHEVRON
OIL TYPE: 15W40
FUEL TYPE: DIESEL

NO. COPIES: 1

LAB#	DATE TAKEN/ TESTED	MRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C	VIS 100° C	WATER % Vol	SOLIDS % Vol	GLYCOL
10219	05/05/95	2560	11	0	1	9	0	3	0	0	0	6	150	0	51	2094	0	985	1187	0	0	0	0	N/A	<1	N/A	11.02	0	N/A	NEG
	05/11/95	8538																												
13217	06/13/95	4302	12	0	2	5	0	3	0	0	0	5	138	0	39	2168	1	983	1135	0	0	0	0	N/A	<1	N/A	10.82	0	N/A	NEG
	06/15/95	12840																												

LAB#	ADDITIONAL CUSTOMER TESTS F-SCOT	TBN	SAE	PARTICLE COUNT RESULTS
10219	0.1	9.2	30	
13217	0.1	8.2	30	

LAB#	ANALYSIS RECOMMENDATIONS	LAB#	ANALYSIS RECOMMENDATIONS
		10219	NO ABNORMAL WEAR DETECTED. NOTE SLIGHTLY LOW VISCOSITY-FUEL CONTENT WITHIN ACCEPTABLE LIMITS. RECOMMEND RESAMPLE AT NORMAL INTERVAL.
		13217	NO ABNORMAL WEAR DETECTED. NOTE: VISCOSITY DATA DOES NOT MATCH INFORMATION PROVIDED. NOTE: TEST RESULTS INDICATE THIS OIL IS IN THE SAE 30 RANGE. RECOMMEND RESAMPLE AT NORMAL INTERVAL.

JIM EVAROFF
BATL PARK SERV.-YELLOWSTONE
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DAVE
BUSCH DIST
MOSCOW, ID 83843

Chevron LubeWatch™
Maintenance Management System

(800) LUBE-808

Chevron Lubricants

11607 EAST TRENT AVENUE, SPOKANE, WASHINGTON 99206, (509) 921-9909, FAX (509) 921-9910

DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: YELLOWSTONE OIL BRAND: CHEVRON

Condition: NORMAL MAKE: DODGE MODEL: RAM 250 OIL TYPE: DELO 400 15W40

Analyst : RGT UNIT SERIAL NO.: 1B7KF26CBSS23913 FUEL TYPE: OTHER NO. COPIES: 2

SAMPLE DATA																																
LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MAGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDEUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C	VIS 100° C	WATER % Vol	SOLIDS % Vol	GLYCOL
14538	05/27/95	728	5	0	0	1	0	2	0	0	0	4	156	0	34	2377	0	994	1178	1	0	0	0	N/A	<1	N/A	12.71	0	N/A	NEG
	07/03/95	13568																												

LAB#	ADDITIONAL CUSTOMER TESTS			PARTICLE COUNT RESULTS
	F-SOOT	TBN	SAE	
14538	0.1	6.8	40	

LAB#	ANALYSIS RECOMMENDATIONS	LAB#	ANALYSIS RECOMMENDATIONS
		14538	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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Chevron LubeWatch™
Maintenance Management System

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11607 EAST TRENT AVENUE, SPOKANE, WASHINGTON 99206, (509) 921-9909, FAX (509) 921-9910

Chevron Lubricants

DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: 251543-YELLOW OIL BRAND: CHEVRON

Condition: NORMAL MAKE: DODGE MODEL: D-250 5.9 OIL TYPE: 15W40

Analyst : RGT UNIT SERIAL NO.: 1B7KF26C85233913 FUEL TYPE: OTHER NO. COPIES: 2

ent Jsr

SAMPLE DATA																														
LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
✓10219	05/05/95	2560	11	0	1	9	0	3	0	0	0	6	150	0	51	2094	0	985	1187	0	0	0	0	N/A	<1	N/A	11.02	0	N/A	NEG
	05/11/95	8538																								^^^^^^				
✓13217	06/13/95	4302	12	0	2	5	0	3	0	0	0	5	138	0	39	2168	1	983	1135	0	0	0	0	N/A	<1	N/A	10.82	0	N/A	NEG
	06/15/95	12840																								^^^^^^				
✓18969	08/17/95	3500	15	0	4	4	0	4	0	0	0	7	143	0	40	2382	0	1020	1205	0	0	0	0	N/A	<1	N/A	12.60	0	N/A	NEG
	08/21/95	16340																												

LAB#	ADDITIONAL CUSTOMER TESTS			PARTICLE COUNT RESULTS
	F-SOOT	TBN	SAE	
10219	0.1	9.2	30	
			^^^^^^	
13217	0.1	8.2	30	
			^^^^^^	
18969	0.2	7.8	40	

LAB#	ANALYSIS RECOMMENDATIONS
10219	NO ABNORMAL WEAR DETECTED. NOTE SLIGHTLY LOW VISCOSITY-FUEL CONTENT WITHIN ACCEPTABLE LIMITS. RECOMMEND RESAMPLE AT NORMAL INTERVAL.

LAB#	ANALYSIS RECOMMENDATIONS
13217	NO ABNORMAL WEAR DETECTED. NOTE: VISCOSITY DATA DOES NOT MATCH INFORMATION PROVIDED. NOTE: TEST RESULTS INDICATE THIS OIL IS IN THE SAE 30 RANGE.
18969	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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Chevron LubeWatch™
Maintenance Management System

(800) [illegible]JBE-808
11607 EAST TRENT AVENUE, SPOKANE, WAS[illegible]GTON 99206, (509) 921-9909, FAX (509) 921-9910

Chevron Lubricants

DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: YELLOWSTONE OIL BRAND: CHEVRON
Condition: NORMAL MAKE: DODGE MODEL: RAM 250 OIL TYPE: DELO 15W40
Analyst : MJZ UNIT SERIAL NO.: 1B7KF26C8SS23913 FUEL TYPE: OTHER NO. COPIES: 2

Unit data

SAMPLE DATA

LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
✓14538	05/27/95	728	5	0	0	1	0	2	0	0	0	4	156	0	34	2377	0	994	1178	1	0	0	0	N/A	<1	N/A	12.71	0	N/A	NEG
	07/03/95	13568																												
✓27488	10/20/95	4797	14	0	4	2	0	3	0	0	0	2	145	0	37	2016	0	1081	1200	0	0	0	0	N/A	<1	N/A	11.13	0	N/A	NEG
	10/23/95	21137																									^^^^^^			

ADDITIONAL CUSTOMER TESTS

LAB#	F-SOOT	TBN	SAE
14538	0.1	6.8	40
27488	0.1	6.7	30
			^^^^^^

PARTICLE COUNT RESULTS

ANALYSIS RECOMMENDATIONS

LAB#

ANALYSIS RECOMMENDATIONS

14538 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

27488 NO ABNORMAL WEAR DETECTED.
NOTE: VISCOSITY DATA DOES NOT MATCH INFORMATION PROVIDED.
NOTE: TEST RESULTS INDICATE THIS OIL IS IN THE SAE 30 RANGE.

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MAMMOTH HOT SPRINGS, WY 82190

CTC CV-100 7/18/95

Chevron LubeWatch™
Maintenance Management System

(800) UBE-808
11607 EAST TRENT AVENUE, SPOKANE, WASHINGTON 99206(509) 921-9909, FAX (509) 921-9910

Chevron Lubricants

DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: YELLOWSTONE OIL BRAND: CHEVRON
Condition: ABNORMAL MAKE: DODGE MODEL: RAM 250 OIL TYPE: DELO 15W40
Analyst : RGT ent. dss UNIT SERIAL NO:. 1B7KF26C8SS23913 FUEL TYPE: OTHER NO. COPIES: 2

SAMPLE DATA

LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
✓14538	05/27/95	728	5	0	0	1	0	2	0	0	0	4	156	0	34	2377	0	994	1178	1	0	0	0	N/A	<1	N/A	12.71	0	N/A	NEG
	07/03/95	13568																												
✓27488	10/20/95	4797	14	0	4	2	0	3	0	0	0	2	145	0	37	2016	0	1081	1200	0	0	0	0	N/A	<1	N/A	11,13	0	N/A	NEG
	10/23/95	21137																									^^^^^^			
✓2682	01/23/96	4796	18	0	3	2	0	3	0	0	0	1	138	4	52	2192	0	810	1023	0	0	0	0	N/A	5.0	N/A	10.42	0	N/A	NEG
	01/26/96	25933																							^^^^		^^^^^^			

ADDITIONAL CUSTOMER TESTS

LAB#	F-SOOT	TBN	SAE
14538	0.1	6.8	40
27488	0.1	6.7	30
			^^^^^^
2682	0.2	4.5	30
			^^^^^^

PARTICLE COUNT RESULTS

ANALYSIS RECOMMENDATIONS

LAB# ANALYSIS RECOMMENDATIONS

14538 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

LAB# ANALYSIS RECOMMENDATIONS

27488 NO ABNORMAL WEAR DETECTED.
NOTE SLIGHTLY LOW VISCOSITY-FUEL CONTENT WITHIN ACCEPTABLE LIMITS.
RECOMMEND RESAMPLE AT NORMAL INTERVAL
2682 NOTE: TEST RESULTS INDICATE PRESENCE OF FUEL DILUTION.
RECOMMEND CHECK FUEL AND INJECTION SYSTEMS FOR SOURCE OF FUEL ENTRY.
RECOMMEND CHANGE LUBE OIL AND LUBE OIL FILTER, IF NOT ALREADY DONE.
RECOMMEND RESAMPLE.

DARYL REECE
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AEL 81
MOSCOW, ID 83844-2040

JIM EVANOFF
NATL PARK SERV.-YELLOWSTONE
MAMMOTH HOT SPRINGS, WY 82190

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Chevron Lubricants

DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: YELLOWSTONE

OIL BRAND: CHEVRON

MAKE: DODGE MODEL: RAM 250 OIL TYPE: DELO 15W40

UNIT SERIAL NO:. 1B7KF26C8SS23913 FUEL TYPE: OTHER NO. COPIES: 2

mr

SAMPLE DATA																														
LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
✓ 14538	05/27/95	728	5	0	0	1	0	2	0	0	0	4	156	0	34	2377	0	994	1178	1	0	0	0	N/A	<1	N/A	12.71	0	N/A	NEG
✓	07/03/95	13568																												
✓ 27488	10/20/95	4797	14	0	4	2	0	3	0	0	0	2	145	0	37	2016	0	1081	1200	0	0	0	0	N/A	<1	N/A	11.13	0	N/A	NEG
	10/23/95	21137																									^^^^^^			
✓ 2682	01/23/96	4796	18	0	3	2	0	3	0	0	0	1	138	4	52	2192	0	810	1023	0	0	0	0	N/A	5.0	N/A	10.42	0	N/A	NEG
	01/26/96	25933																							^^^^		^^^^^^			

LAB#	ADDITIONAL CUSTOMER TESTS			PARTICLE COUNT RESULTS
	E-SOOT	TBN	SAE	
14538	0.1	6.8	40	
27488	0.1	6.7	30	
			^^^^^^	
2682	0.2	4.5	30	
			^^^^^^	

LAB#	ANALYSIS RECOMMENDATIONS
14538	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

LAB#	ANALYSIS RECOMMENDATIONS
27488	NO ABNORMAL WEAR DETECTED.
	NOTE SLIGHTLY LOW VISCOSITY-FUEL CONTENT WITHIN ACCEPTABLE LIMITS.
	RECOMMEND RESAMPLE AT NORMAL INTERVAL
2682	NOTE: TEST RESULTS INDICATE PRESENCE OF FUEL DILUTION.
	RECOMMEND CHECK FUEL AND INJECTION SYSTEMS FOR SOURCE OF FUEL ENTRY.
	RECOMMEND CHANGE LUBE OIL AND LUBE OIL FILTER, IF NOT ALREADY DONE.
	RECOMMEND RESAMPLE.

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11607 EAST TRENT AVENUE, SPOKANE, WASHINGTON 99206 (509) 921-9909, FAX (509) 921-9910

Chevron lubricants

CUSTOMER NO.: 19562 UNIT NO.: PARK
Condition: NORMAL
Analyst : RGT

DESCRIPTION: ENGINE
MAKE: DODGE MODEL: 2500
UNIT SERIAL NO:.

OIL BRAND: CHEVRON
OIL TYPE: DELO 15W40
FUEL TYPE: DIESEL

NO. COPIES: 2

SAMPLE DATA

LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
3844	02/17/95	2313	35	1	6	25	0	3	0	0	0	25	201	7	748	838	94	1208	1477	1	0	0	0	N/A	<1	N/A	12.58	0	0.1	NEG
	02/24/95	2313										^^^^																		
8425	03/28/95	3662	20	1	3	24	0	4	0	0	0	10	140	1	97	2161	17	983	1127	0	0	0	0	N/A	<1	N/A	12.65	0	N/A	NEG
	04/24/95	5978																												
7279	03/13/96	3600	15	1	4	2	0	3	0	0	0	1	154	2	48	2051	0	1006	1217	0	0	0	0	N/A	<1	N/A	12.54	0	0.1	NEG
	03/18/96	29525																												

ADDITIONAL CUSTOMER TESTS

LAB#	F-SOOT	TBN	SAE
3844	0.1	7.7	40
8425	0.1	5.3	40
7279	0.1	5.0	40

PARTICLE COUNT RESULTS

ANALYSIS RECOMMENDATIONS

LAB# 3844 SILICON LEVEL IS HIGH - POSSIBLY FROM NORMAL ENGINE BREAK-IN.
RECOMMEND CHANGE LUBE OIL AND LUBE OIL FILTER, IF NOT ALREADY DONE.
RECOMMEND RESAMPLE AT NORMAL INTERVAL

ANALYSIS RECOMMENDATIONS

LAB# 8425 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

LAB# 7279 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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DESCRIPTION: NEW OIL SAMPLE

CUSTOMER NO.: 2000336 UNIT NO.: YELLOWSTONE

Condition: NORMAL

Analyst : RGT

NEW OIL

MAKE: MODEL:

UNIT SERIAL NO.:

OIL BRAND: ?

OIL TYPE: ?

FUEL TYPE:

NO. COPIES: 2

SAMPLE DATA

LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MAGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDEUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C	VIS 100° C	WATER % Vol	SOLIDS % Vol	GLYCOL
14537	06/28/95 ?		0	0	0	0	0	0	0	0	0	4	155	0	33	2448	2	977	1150	1	0	0	0	N/A	<1	N/A	14.95	0	N/A	NEG
	07/03/95 ?																													

ADDITIONAL CUSTOMER TESTS

LAB#	F-SOOT	TBN	SAE
14537	N/A	8.3	40

PARTICLE COUNT RESULTS

ANALYSIS RECOMMENDATIONS

LAB#	ANALYSIS RECOMMENDATIONS
14537	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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Chevron Lubricants

DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: YELLOWSTONE OIL BRAND: CHEVRON
Condition: NORMAL MAKE: DODGE MODEL: D-250 5.9 OIL TYPE: 15W40
Analyst : RGT UNIT SERIAL NO:. 1B7KF26C85233913 FUEL TYPE: OTHER NO. COPIES: 2

SAMPLE DATA																														
LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
27488	10/20/95	4797	14	0	4	2	0	3	0	0	0	2	145	0	37	2016	0	1081	1200	0	0	0	0	N/A	<1	N/A	11.13	0	N/A	NEG
	10/23/95	21137																									^^^^^^			
2682	01/23/96	4796	18	0	3	2	0	3	0	0	0	1	138	4	52	2192	0	810	1023	0	0	0	0	N/A	5.0	N/A	10.42	0	N/A	NEG
	01/26/96	25933																							^^^^		^^^^^^			
7279	03/13/96	3600	15	1	4	2	0	3	0	0	0	1	154	2	48	2051	0	1006	1217	0	0	0	0	N/A	<1	N/A	12.54	0	0.1	NEG
	03/18/96	29525																												
16174	06/04/96	33542	14	1	4	2	0	3	0	0	0	1	148	2	48	2011	0	980	1119	0	0	0	0	N/A	<1	N/A	12.55	0	N/A	NEG
	06/07/96	33542																												

LAB#	ADDITIONAL CUSTOMER TESTS			PARTICLE COUNT RESULTS
	F-SOOT	TBN	SAE	
27488	0.1	6.7	30	
			^^^^^^	
2682	0.2	4.5	30	
			^^^^^^	
7279	0.1	5.0	40	
16174	0.2	5.0	40	

LAB#	ANALYSIS RECOMMENDATIONS
27488	NO ABNORMAL WEAR DETECTED.
	NOTE SLIGHTLY LOW VISCOSITY-FUEL CONTENT WITHIN ACCEPTABLE LIMITS.
	RECOMMEND RESAMPLE AT NORMAL INTERVAL
2682	NOTE: TEST RESULTS INDICATE PRESENCE OF FUEL DILUTION.
	RECOMMEND CHECK FUEL AND INJECTION SYSTEMS FOR SOURCE OF FUEL ENTRY.
	RECOMMEND CHANGE LUBE OIL AND LUBE OIL FILTER, IF NOT ALREADY DONE.

LAB#	ANALYSIS RECOMMENDATIONS
7279	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
16174	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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Chevron Lubricants

DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: PARK OIL BRAND: CHEVRON
Condition: NORMAL MAKE: DODGE MODEL: D-250 5.9 OIL TYPE: DELO 15W40
Analyst : RGT 876 UNIT SERIAL NO:. 1B7KF26C85233913 FUEL TYPE: GASOLINE NO. COPIES: 2

SAMPLE DATA																													
LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
2682	01/23/96	4796	18	0	3	2	0	3	0	0	0	1	138	4	52	2192	0	810	1023	0	0	0	0	N/A	5.0	N/A	10.42	0	N/A	NEG
	01/26/96	25933																							^^^^		^^^^^^			
7279	03/13/96	3600	15	1	4	2	0	3	0	0	0	1	154	2	48	2051	0	1006	1217	0	0	0	0	N/A	<1	N/A	12.54	0	0.1	NEG
	03/18/96	29525																												
16174	06/04/96	31542	14	1	4	2	0	3	0	0	0	1	148	2	48	2011	0	980	1119	0	0	0	0	N/A	<1	N/A	12.55	0	N/A	NEG
	06/07/96	33542																												
18463	06/27/96	2512	10	0	3	2	0	3	0	0	0	1	142	1	49	2270	0	1056	1206	0	0	0	0	N/A	<1	N/A	12.99	0	N/A	NEG
	07/01/96	36012																												

LAB#	ADDITIONAL CUSTOMER TESTS			PARTICLE COUNT RESULTS
	%-SOOT	TBN	SAE	
2682	0.2	4.5	30	
			^^^^^^	
7279	0.1	5.0	40	
16174	0.2	5.0	40	
18463	0.2	5.4	40	

LAB#	ANALYSIS RECOMMENDATIONS
2682	NOTE: TEST RESULTS INDICATE PRESENCE OF FUEL DILUTION. RECOMMEND CHECK FUEL AND INJECTION SYSTEMS FOR SOURCE OF FUEL ENTRY. RECOMMEND CHANGE LUBE OIL AND LUBE OIL FILTER, IF NOT ALREADY DONE.
7279	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

LAB#	ANALYSIS RECOMMENDATIONS
16174	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
18463	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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CUSTOMER NO.: 2000336 UNIT NO.: PARK
DESCRIPTION: ENGINE
OIL BRAND: CHEVRON
Condition: NORMAL MAKE: DODGE MODEL: D-250 5.9 OIL TYPE: DELO 15W40
Analyst : RGT UNIT SERIAL NO:. 1B7KF26C85233913 FUEL TYPE: GASOLINE NO. COPIES: 2

SAMPLE DATA

LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
7279	03/13/96	3600	15	1	4	2	0	3	0	0	0	1	154	2	48	2051	0	1006	1217	0	0	0	0	N/A	<1	N/A	12.54	0	0.1	NEG
	03/18/96	29525																												
16174	06/04/96	31542	14	1	4	2	0	3	0	0	0	1	148	2	48	2011	0	980	1119	0	0	0	0	N/A	<1	N/A	12.55	0	N/A	NEG
	06/07/96	33542																												
18463	06/27/96	2512	10	0	3	2	0	3	0	0	0	1	142	1	49	2270	0	1056	1206	0	0	0	0	N/A	<1	N/A	12.99	0	N/A	NEG
	07/01/96	36012																												
23980	08/16/96	3239	11	0	3	2	0	2	0	0	0	3	125	2	95	2175	0	1015	1198	0	0	0	0	N/A	<1	N/A	12.80	0	N/A	NEG
	08/26/96	39251																												

LAB#	ADDITIONAL CUSTOMER TESTS										PARTICLE COUNT RESULTS
	F-SOOT	TBN	SAE								
7279	0.1	5.0	40								
16174	0.2	5.0	40								
18463	0.2	5.4	40								
23980	0.1	5.2	40								

LAB#	ANALYSIS RECOMMENDATIONS
7279	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
16174	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

LAB#	ANALYSIS RECOMMENDATIONS
18463	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
23980	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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Chevron
Global Lubricants and Technology Marketing

CUSTOMER NO.: 2000336 UNIT NO.: PARK
DESCRIPTION: ENGINE
OIL BRAND: CHEVRON
Condition: NORMAL
MAKE: DODGE MODEL: D-250 5.9 OIL TYPE: DELO 15W40
Analyst : RGT
UNIT SERIAL NO:. 1B7KF26C85233913 FUEL TYPE: GASOLINE NO. COPIES: 2

SAMPLE DATA

LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS @7 C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
16174	06/04/96	31542	14	1	4	2	0	3	0	0	0	1	148	2	48	2011	0	980	1119	0	0	0	0	N/A	<1	N/A	12.55	0	N/A	NEG
	06/07/96	33542																												
18463	06/27/96	2512	10	0	3	2	0	3	0	0	0	1	142	1	49	2270	0	1056	1206	0	0	0	0	N/A	<1	N/A	12.99	0	N/A	NEG
	07/01/96	36012																												
23980	08/16/96	3239	11	0	3	2	0	2	0	0	0	3	125	2	95	2175	0	1015	1198	0	0	0	0	N/A	<1	N/A	12.80	0	N/A	NEG
	08/26/96	39251																												
28489	09/27/96	6445	16	0	4	2	0	2	0	0	0	3	147	3	53	2213	0	1039	1221	0	0	0	0	N/A	<1	N/A	12.57	0	N/A	NEG
	10/07/96	45696																												

ADDITIONAL CUSTOMER TESTS

LAB#	F-SOOT	TBN	SAE
16174	0.2	5.0	40
18463	0.2	5.4	40
23980	0.1	5.2	40
28489	0.1	5.0	40

PARTICLE COUNT RESULTS

ANALYSIS RECOMMENDATIONS

LAB# ANALYSIS RECOMMENDATIONS

16174 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

18463 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

23980 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

28489 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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Global Lubricants and Technology Marketing

DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: PARK OIL BRAND: CHEVRON

Condition: NORMAL MAKE: DODGE MODEL: D-250 5.9 OIL TYPE: DELO 15W40

Analyst : RGT UNIT SERIAL NO:. 1B7KF26C85233913 FUEL TYPE: OTHER NO. COPIES: 2

SAMPLE DATA																														
LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
18463	06/27/96	2512	10	0	3	2	0	3	0	0	0	1	142	1	49	2270	0	1056	1206	0	0	0	0	N/A	<1	N/A	12.99	0	N/A	NEG
	07/01/96	36012																												
23980	08/16/96	3239	11	0	3	2	0	2	0	0	0	3	125	2	95	2175	0	1015	1198	0	0	0	0	N/A	<1	N/A	12.80	0	N/A	NEG
	08/26/96	39251																												
28489	09/27/96	6445	16	0	4	2	0	2	0	0	0	3	147	3	53	2213	0	1039	1221	0	0	0	0	N/A	<1	N/A	12.57	0	N/A	NEG
	10/07/96	45696																												
32367	11/05/96	3995	11	0	3	1	0	3	0	0	0	3	151	2	46	2310	0	1056	1224	0	0	0	0	N/A	<1	N/A	12.85	0	N/A	NEG
	11/11/96	48695																												

LAB#	ADDITIONAL CUSTOMER TESTS			PARTICLE COUNT RESULTS
	F-SOOT	TBN	SAE	
18463	0.2	5.4	40	
23980	0.1	5.2	40	
28489	0.1	5.0	40	
32367	0.1	5.8	40	

LAB#	ANALYSIS RECOMMENDATIONS
18463	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
23980	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

LAB#	ANALYSIS RECOMMENDATIONS
28489	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
32367	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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Chevron Texaco
Global Lubricants and Technology Marketing

DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: PARK OIL BRAND: CHEVRON

Condition: NORMAL MAKE: DODGE MODEL: D-250 5.9 OIL TYPE: DELO 400 15W40

Analyst : RGT UNIT SERIAL NO:. 1B7KF26C85233913 FUEL TYPE: OTHER NO. COPIES: 2

SAMPLE DATA			SPECTROCHEMICAL ANALYSIS - PARTS PER MILLION																					PHYSICAL PROPERTY DATA						
LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
23980	08/16/96	3239	11	0	3	2	0	2	0	0	0	3	125	2	95	2175	0	1015	1198	0	0	0	0	N/A	<1	N/A	12.80	0	N/A	NEG
	08/26/96	39251																												
28489	09/27/96	6445	16	0	4	2	0	2	0	0	0	3	147	3	53	2213	0	1039	1221	0	0	0	0	N/A	<1	N/A	12.57	0	N/A	NEG
	10/07/96	45696																												
32367	11/05/96	3995	11	0	3	1	0	3	0	0	0	3	151	2	46	2310	0	1056	1224	0	0	0	0	N/A	<1	N/A	12.85	0	N/A	NEG
	11/11/96	48695																												
9720	03/31/97	?	14	0	3	2	0	2	0	0	0	3	166	3	20	2236	0	1081	1213	0	0	0	0	N/A	<1	N/A	12.92	0	N/A	NEG
	04/03/97	55378																												

LAB#	ADDITIONAL CUSTOMER TESTS			PARTICLE COUNT RESULTS
	F-SOOT	TBN	SAE	
23980	0.1	5.2	40	
28489	0.1	5.0	40	
32367	0.1	5.8	40	
9720	0.1	6.0	40	

LAB#	ANALYSIS RECOMMENDATIONS
23980	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
28489	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

LAB#	ANALYSIS RECOMMENDATIONS
32367	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
9720	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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Chevron
Global Lubricants and Technology Marketing

CUSTOMER NO.: 2000336 UNIT NO.: PARK DESCRIPTION: ENGINE
Condition: NORMAL MAKE: DODGE MODEL: D-250 5.9 OIL BRAND: CHEVRON
Analyst : RGT ent JPV UNIT SERIAL NO:. 1B7KF26C85233913 OIL TYPE: DELO 400 15W40
FUEL TYPE: OTHER NO. COPIES: 2

SAMPLE DATA																														
LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
✓ 23980	08/16/96	3239	11	0	3	2	0	2	0	0	0	3	125	2	95	2175	0	1015	1198	0	0	0	0	N/A	<1	N/A	12.80	0	N/A	NEG
	08/26/96	39251																												
✓ 28489	09/27/96	6445	16	0	4	2	0	2	0	0	0	3	147	3	53	2213	0	1039	1221	0	0	0	0	N/A	<1	N/A	12.57	0	N/A	NEG
	10/07/96	45696																												
✓ 32367	11/05/96	3995	11	0	3	1	0	3	0	0	0	3	151	2	46	2310	0	1056	1224	0	0	0	0	N/A	<1	N/A	12.85	0	N/A	NEG
	11/11/96	48695																												
✓ 9720	03/31/97	?	14	0	3	2	0	2	0	0	0	3	166	3	20	2236	0	1081	1213	0	0	0	0	N/A	<1	N/A	12.92	0	N/A	NEG
	04/03/97	55378																												

LAB#	ADDITIONAL CUSTOMER TESTS			PARTICLE COUNT RESULTS
	F-SOOT	TBN	SAE	
23980	0.1	5.2	40	
28489	0.1	5.0	40	
32367	0.1	5.8	40	
9720	0.1	6.0	40	

LAB#	ANALYSIS RECOMMENDATIONS
23980	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
28489	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

LAB#	ANALYSIS RECOMMENDATIONS
32367	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
9720	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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Chevron
Global Lubricants and Technology Marketing

DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: PARK OIL BRAND: CHEVRON

Condition: NORMAL MAKE: DODGE MODEL: D-250 5.9 OIL TYPE: DELO 400 15W40

Analyst : RGT UNIT SERIAL NO:. 1B7KF26C85233913 FUEL TYPE: OTHER NO. COPIES: 2

ent dsr

SAMPLE DATA

LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
28489	09/27/96	6445	16	0	4	2	0	2	0	0	0	3	147	3	53	2213	0	1039	1221	0	0	0	0	N/A	<1	N/A	12.57	0	N/A	NEG
	10/07/96	45696																												
32367	11/05/96	3995	11	0	3	1	0	3	0	0	0	3	151	2	46	2310	0	1056	1224	0	0	0	0	N/A	<1	N/A	12.85	0	N/A	NEG
	11/11/96	48695																												
9720	03/31/97	?	14	0	3	2	0	2	0	0	0	3	166	3	20	2236	0	1081	1213	0	0	0	0	N/A	<1	N/A	12.92	0	N/A	NEG
	04/03/97	55378																												
13542	05/01/97	58493	9	1	2	2	0	1	0	0	0	2	146	3	12	2215	0	1014	1180	0	0	0	0	N/A	<1	N/A	13.02	0	N/A	NEG
	05/08/97	58493																												

LAB#	ADDITIONAL CUSTOMER TESTS			PARTICLE COUNT RESULTS
	F-SOOT	TBN	SAE	
28489	0.1	5.0	40	
32367	0.1	5.8	40	
9720	0.1	6.0	40	
13542	0.1	6.1	40	

LAB#	ANALYSIS RECOMMENDATIONS
28489	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
32367	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

LAB#	ANALYSIS RECOMMENDATIONS
9720	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
13542	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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Chevron
Global Lubricants and Technology Marketing

CUSTOMER NO.: 2000336 UNIT NO.: YELLOWSTONE DESCRIPTION: ENGINE
Condition: NORMAL
Analyst : RGT end jar
MAKE: DODGE MODEL: D-250 5.9 OIL BRAND: CHEVRON
UNIT SERIAL NO:. 1B7KF26C85233913 OIL TYPE: DELO 400 15W40
FUEL TYPE: OTHER NO. COPIES: 2

SAMPLE DATA																														
LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
32367	11/05/96	3995	11	0	3	1	0	3	0	0	0	3	151	2	46	2310	0	1056	1224	0	0	0	0	N/A	<1	N/A	12.85	0	N/A	NEG
	11/11/96	48695																												
9720	03/31/97	?	14	0	3	2	0	2	0	0	0	3	166	3	20	2236	0	1081	1213	0	0	0	0	N/A	<1	N/A	12.92	0	N/A	NEG
	04/03/97	55378																												
13542	05/01/97	58493	9	1	2	2	0	1	0	0	0	2	146	3	12	2215	0	1014	1180	0	0	0	0	N/A	<1	N/A	13.02	0	N/A	NEG
	05/08/97	58493																												
18341	06/13/97	3501	11	0	3	2	0	1	0	0	0	3	154	3	15	2319	0	1013	1180	0	0	0	0	N/A	<1	N/A	12.74	0	N/A	NEG
	06/19/97	61994																												

LAB#	ADDITIONAL CUSTOMER TESTS			PARTICLE COUNT RESULTS
	F-SOOT	TBN	SAE	
32367	0.1	5.8	40	
9720	0.1	6.0	40	
13542	0.1	6.1	40	
18341	0.1	6.4	40	

LAB# ANALYSIS RECOMMENDATIONS

32367 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

9720 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

LAB# ANALYSIS RECOMMENDATIONS

13542 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

18341 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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Chevron
Global Lubricants and Technology Marketing

DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: YELLOWSTONE
Condition: NORMAL
Analyst : RGT

MAKE: DODGE MODEL: D-250 5.9
UNIT SERIAL NO:. 1B7KF26C85233913

OIL BRAND: CHEVRON
O'L TYPE: DELO 400 15W40
FUEL TYPE: OTHER NO. COPIES: 2

SAMPLE DATA																														
LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
9720	03/31/97	?	14	0	3	2	0	2	0	0	0	3	166	3	20	2236	0	1081	1213	0	0	0	0	N/A	<1	N/A	12.92	0	N/A	NEG
	04/03/97	55378																												
13542	05/01/97	58493	9	1	2	2	0	1	0	0	0	2	146	3	12	2215	0	1014	1180	0	0	0	0	N/A	<1	N/A	13.02	0	N/A	NEG
	05/08/97	58493																												
18341	06/13/97	3501	11	0	3	2	0	1	0	0	0	3	154	3	15	2319	0	1013	1180	0	0	0	0	N/A	<1	N/A	12.74	0	N/A	NEG
	06/19/97	61994																												
21459	07/17/97	2249	6	0	2	1	0	1	0	0	0	2	147	3	13	2189	0	1011	1176	0	0	0	0	N/A	<1	N/A	12.69	0	N/A	NEG
	07/21/97	64243																												

LAB#	ADDITIONAL CUSTOMER TESTS			PARTICLE COUNT RESULTS
	F-SOOT	TBN	SAE	
9720	0.1	6.0	40	
13542	0.1	6.1	40	
18341	0.1	6.4	40	
21459	0.1	6.4	40	

LAB# ANALYSIS RECOMMENDATIONS

9720 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

13542 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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LAB# ANALYSIS RECOMMENDATIONS

18341 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

21459 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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Chevron
Global Lubricants and Technology Marketing

CRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: YELLOWSTONE OIL BRAND: CHEVRON
Condition: NORMAL MAKE: DODGE MODEL: D-250 5.9 OIL TYPE: DELO 400 15W40
Analyst : RGT UNIT SERIAL NO:. 1B7KF26C85233913 FUEL TYPE: OTHER NO. COPIES: 2

SAMPLE DATA			SPECTROMETRIC ANALYSIS																					PHYSICAL PROPERTY DATA						
LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
9720	03/31/97	?	14	0	3	2	0	2	0	0	0	3	166	3	20	2236	0	1081	1213	0	0	0	0	N/A	<1	N/A	12.92	0	N/A	NEG
	04/03/97	55378																												
13542	05/01/97	58493	9	1	2	2	0	1	0	0	0	2	146	3	12	2215	0	1014	1180	0	0	0	0	N/A	<1	N/A	13.02	0	N/A	NEG
	05/08/97	58493																												
18341	06/13/97	3501	11	0	3	2	0	1	0	0	0	3	154	3	15	2319	0	1013	1180	0	0	0	0	N/A	<1	N/A	12.74	0	N/A	NEG
	06/19/97	61994																												
21459	07/17/97	2249	6	0	2	1	0	1	0	0	0	2	147	3	13	2189	0	1011	1176	0	0	0	0	N/A	<1	N/A	12.69	0	N/A	NEG
	07/21/97	64243																												

LAB#	ADDITIONAL CUSTOMER TESTS			PARTICLE COUNT RESULTS
	F-SOOT	TBN	SAE	
9720	0.1	6.0	40	
13542	0.1	6.1	40	
18341	0.1	6.4	40	
21459	0.1	6.4	40	

entered RGT

LAB#	ANALYSIS RECOMMENDATIONS
9720	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
13542	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

LAB#	ANALYSIS RECOMMENDATIONS
18341	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
21459	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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Chevron
Global Lubricants and Technology Marketing

DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: YELLOWSTONE OIL BRAND: CHEVRON

Condition: NORMAL MAKE: DODGE MODEL: D-250 5.9 OIL TYPE: DELO 400 15W40

Analyst : RGT UNIT SERIAL NO:. 1B7KF26C85233913 FUEL TYPE: OTHER NO. COPIES: 2

SAMPLE DATA

LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
13542	05/01/97	58493	9	1	2	2	0	1	0	0	0	2	146	3	12	2215	0	1014	1180	0	0	0	0	N/A	<1	N/A	13.02	0	N/A	NEG
	05/08/97	58493																												
18341	06/13/97	3501	11	0	3	2	0	1	0	0	0	3	154	3	15	2319	0	1013	1180	0	0	0	0	N/A	<1	N/A	12.74	0	N/A	NEG
	06/19/97	61994																												
21459	07/17/97	2249	6	0	2	1	0	1	0	0	0	2	147	3	13	2189	0	1011	1176	0	0	0	0	N/A	<1	N/A	12.69	0	N/A	NEG
	07/21/97	64243																												
27385	09/05/97	4574	13	0	3	2	0	2	0	0	0	3	131	3	37	2190	0	1126	1288	0	0	0	0	N/A	<1	N/A	12.53	0	N/A	NEG
	09/10/97	68074																												

ADDITIONAL CUSTOMER TESTS

LAB#	F-SOOT	TBN	SAE
13542	0.1	6.1	40
18341	0.1	6.4	40
21459	0.1	6.4	40
27385	0.1	6.0	40

PARTICLE COUNT RESULTS

ANALYSIS RECOMMENDATIONS

LAB# 13542 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

LAB# 18341 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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JML 85
MOSCOW, ID 83844-2040

ANALYSIS RECOMMENDATIONS

LAB# 21459 RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

LAB# 27385 RESULTS OF TEST PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: YELLOWSTONE OIL BRAND: CHEVRON
Condition: NORMAL MAKE: DODGE MODEL: D-250 5 9 OIL TYPE: DELO 400 15W40
Analyst : RGT UNIT SERIAL NO:. 1B7KF26C85233913 FUEL TYPE: OTHER NO. COPIES: 2

SAMPLE DATA

LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
18341	06/13/97	3501	11	0	3	2	0	1	0	0	0	3	154	3	15	2319	0	1013	1180	0	0	0	0	N/A	<1	N/A	12.74	0	N/A	NEG
	06/19/97	61994																												
21459	07/17/97	2249	6	0	2	1	0	1	0	0	0	2	147	3	13	2189	0	1011	1176	0	0	0	0	N/A	<1	N/A	12.69	0	N/A	NEG
	07/21/97	64243																												
27385	09/05/97	4574	13	0	3	2	0	2	0	0	0	3	131	3	37	2190	0	1126	1288	0	0	0	0	N/A	<1	N/A	12.53	0	N/A	NEG
	09/10/97	68074																												
28698	09/17/97	2636	11	0	3	1	0	1	0	0	0	2	144	4	14	2086	0	1120	1293	0	0	0	0	N/A	<1	N/A	13.06	0	N/A	NEG
	09/22/97	70710																												

LAB#	ADDITIONAL CUSTOMER TESTS			PARTICLE COUNT RESULTS
	F-SOOT	TBN	SAE	
18341	0.1	6.4	40	
21459	0.1	6.4	40	
27385	0.1	6.0	40	
28698	0.1	7.1	40	

LAB#	ANALYSIS RECOMMENDATIONS
18341	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
21459	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

LAB#	ANALYSIS RECOMMENDATIONS
27385	RESULTS OF TEST PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
28698	RESULTS OF TEST PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

JOSEPH THOMPSON
BIO & AG ENG
UNIVERSITY OF IDAHO
JML 85
MOSCOW, ID 83844-2040

JIM EVANOFF
NATL PARK SERV.-YELLOWSTONE
MAMMOTH HOT SPRINGS, WY 82190

CTC CV-100 Rev. 6/96

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11607 EAST TRENT AVENUE, SPOKANE, WASHI. JN 99206 (509) 921-9909, FAX (509) 921-9910

Chevron
Global Lubricants and Technology Marketing

DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: YELLOWSTONE OIL BRAND: CHEVRON
Condition: NORMAL MAKE: DODGE MODEL: D-250 5.9 OIL TYPE: DELO 400 15W40
Analyst : RGT UNIT SERIAL NO:. 1B7KF26C85233913 FUEL TYPE: OTHER NO. COPIES: 2

SAMPLE DATA																														
LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
21459	07/17/97	2249	6	0	2	1	0	1	0	0	0	2	147	3	13	2189	0	1011	1176	0	0	0	0	N/A	<1	N/A	12.69	0	N/A	NEG
	07/21/97	64243																												
27385	09/05/97	4574	13	0	3	2	0	2	0	0	0	3	131	3	37	2190	0	1126	1288	0	0	0	0	N/A	<1	N/A	12.53	0	N/A	NEG
	09/10/97	68074																												
28698	09/17/97	2636	11	0	3	1	0	1	0	0	0	2	144	4	14	2086	0	1120	1293	0	0	0	0	N/A	<1	N/A	13.06	0	N/A	NEG
	09/22/97	70710																												
35674	11/10/97	4111	11	1	4	1	0	1	0	0	0	3	136	4	12	2083	0	1104	1280	0	0	0	0	N/A	<1	N/A	12.70	0	N/A	NEG
	11/17/97	74821																												

LAB#	ADDITIONAL CUSTOMER TESTS			PARTICLE COUNT RESULTS
	F-SOOT	TBN	SAE	
21459	0.1	6.4	40	
27385	0.1	6.0	40	
28698	0.1	7.1	40	
35674	0.1	6.3	40	

LAB#	ANALYSIS RECOMMENDATIONS
21459	RESULTS OF TESTS PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
27385	RESULTS OF TEST PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

JOSEPH THOMPSON
BIO & AG ENG
UNIVERSITY OF IDAHO
JML 85
MOSCOW, ID 83844-2040

LAB#	ANALYSIS RECOMMENDATIONS
28698	RESULTS OF TEST PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
35674	RESULTS OF TEST PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

JIM EVANOFF
NATL PARK SERV.-YELLOWSTONE
MAMMOTH HOT SPRINGS, WY 82190

CTC CV-100 Rev. 6/96

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11607 EAST TRENT AVENUE, SPOKANE, WASHINGTON 99206 (509) 921-9909, FAX (509) 921-9910

Chevron
Global Lubricants and Technology Marketing

DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: YELLOWSTONE OIL BRAND: CHEVRON
Condition: ABNORMAL MAKE: DODGE MODEL: D-2500 5.9 OIL TYPE: DELO 400 15W40
Analyst : RGT UNIT SERIAL NO:. 1B7KF26C85233913 FUEL TYPE: OTHER NO. COPIES: 2

SAMPLE DATA																														
LAB#	DATE TAKEN/ TESTED	HRS/M OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
27385	09/05/97	4574	13	0	3	2	0	2	0	0	0	3	131	3	37	2190	0	1126	1288	0	0	0	0	N/A	<1	N/A	12.53	0	N/A	NEG
	09/10/97	68074																												
28698	09/17/97	2636	11	0	3	1	0	1	0	0	0	2	144	4	14	2086	0	1120	1293	0	0	0	0	N/A	<1	N/A	13.06	0	N/A	NEG
	09/22/97	70710																												
35674	11/10/97	4111	11	1	4	1	0	1	0	0	0	3	136	4	12	2083	0	1104	1280	0	0	0	0	N/A	<1	N/A	12.70	0	N/A	NEG
	11/17/97	74821																												
13691	04/27/98	?	12	0	3	1	0	2	0	0	0	4	153	7	12	2228	0	1122	1269	0	0	0	0	N/A	<1	N/A	11.99	0	N/A	NEG
	04/30/98	82807																									^^^^^^			

LAB#	ADDITIONAL CUSTOMER TESTS			PARTICLE COUNT RESULTS
	F-SOOT	TBN	SAE	
27385	0.1	6.0	40	
28698	0.1	7.1	40	
35674	0.1	6.3	40	
13691	0.3	7.1	30	
			^^^^^^	

LAB# ANALYSIS RECOMMENDATIONS

27385 RESULTS OF TEST PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

28698 RESULTS OF TEST PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

JEFF TABERSKI
BIO & AG ENG
UNIVERSITY OF IDAHO
JML 81
MOSCOW, ID 83844-2060

LAB# ANALYSIS RECOMMENDATIONS

35674 RESULTS OF TEST PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

13691 NO ABNORMAL WEAR DETECTED.
NOTE: VISCOSITY DATA DOES NOT MATCH INFORMATION PROVIDED.
NOTE: TEST RESULTS INDICATE THIS OIL IS IN THE SAE 30 RANGE.
RECOMMEND RESAMPLE AT NEXT OIL DRAIN INTERVAL.

JIM EVANOFF
NATL PARK SERV.-YELLOWSTONE
MAMMOTH HOT SPRINGS, WY 82190

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Chevron
Global Lubricants and Technology Marketing

DESCRIPTION: ENGINE

CUSTOMER NO.: 2000336 UNIT NO.: YELLOWSTONE OIL BRAND: CHEVRON

Condition: NORMAL MAKE: DODGE MODEL: D-2500 5.9 OIL TYPE: DELO 400 15W40

Analyst : RGT UNIT SERIAL NO:. 1B7KF26C85233913/1-251543 FUEL TYPE: OTHER NO. COPIES: 2

SAMPLE DATA																														
LAB#	DATE TAKEN/ TESTED	HRS/MI OIL UNIT	IRON	CHROMIUM	LEAD	COPPER	TIN	ALUMINUM	NICKEL	SILVER	MANGANESE	SILICON	BORON	SODIUM	MAGNESIUM	CALCIUM	BARIUM	PHOSPHORUS	ZINC	MOLYBDENUM	TITANIUM	VANADIUM	POTASSIUM	FLASH	FUEL % Vol	VIS 40° C cSt	VIS 100° C cSt	WATER % Vol	SOLIDS % Vol	GLYCOL
35674	11/10/97	4111	11	1	4	1	0	1	0	0	0	3	136	4	12	2083	0	1104	1280	0	0	0	0	N/A	<1	N/A	12.70	0	N/A	NEG
	11/17/97	74821																												
13691	04/27/98	?	12	0	3	1	0	2	0	0	0	4	153	7	12	2228	0	1122	1269	0	0	0	0	N/A	<1	N/A	11.99	0	N/A	NEG
	04/30/98	82807																									------			
15287	05/11/98	?	6	0	2	1	0	1	0	0	0	2	157	6	9	1862	0	1131	1235	0	0	0	0	N/A	<1	N/A	12.84	0	N/A	NEG
	05/15/98	84732																												
21663	07/07/98	?	10	0	3	1	0	1	0	0	0	3	157	6	12	2116	0	1124	1301	0	0	0	0	N/A	<1	N/A	12.73	0	N/A	NEG
	07/10/98	93000																												

LAB#	ADDITIONAL CUSTOMER TESTS			PARTICLE COUNT RESULTS
	F-SOOT	TBN	SAE	
35674	0.1	6.5	40	
13691	0.3	7.1	30	

15287	0.1	7.2	40	
21663	0.1	7.6	40	

LAB#	ANALYSIS RECOMMENDATIONS
35674	RESULTS OF TEST PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
13691	NO ABNORMAL WEAR DETECTED. NOTE: VISCOSITY DATA DOES NOT MATCH INFORMATION PROVIDED. NOTE: TEST RESULTS INDICATE THIS OIL IS IN THE SAE 30 RANGE.

LAB#	ANALYSIS RECOMMENDATIONS
15287	RESULTS OF TEST PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.
21663	RESULTS OF TEST PERFORMED INDICATE NO CORRECTIVE ACTION REQUIRED.

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BIO & AG ENG
UNIVERSITY OF IDAHO
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MOSCOW, ID 83844-2060

JIM EVANOFF
NATL PARK SERV.-YELLOWSTONE
MAMMOTH HOT SPRINGS, WY 82190

CTC CV-100 Rev. 6/96

Appendix E

Engine Teardown Report

Critical Engine Measurements

ENGINE TEARDOWN WORKSHEET
YELLOWSTONE 1995 DODGE
July 1998

Cylinder Head		
Injectors		less carbon than usual all parts - less carbon than would be expected from diesel
Valves		normal - do not need grinding, deposits very low
Valve Rotators		OK
Cam Shaft		slight pitting on 2 lobes, others not a problem normal wear, OK
Cam Thrust Plate		slight wear around outer edge - no wear on inner edge
Rocker		OK
Pads		OK
Shafts		OK
Lever Bores		OK
Bodies		OK
Push Tubes		Normal
Tappets		Some very slight pitting to match cam
Head Gasket		good, no leakage, no coolant, no blow across
Block		
Main Bearings		very good, no wear
Crankshaft		slight seep of oil from rear main; slightly more than front Eceptionally good journals, very slight grooving at seals
Pistons		Clean, some deposits on top land
Rings		
Top		even wear in center, no contact on edges, 10% each
2nd		25% face contact, clean
Oil		no apparent wear
Piston Pins		no wear, normal
Liners		honing marks apparent throughout; slight deposit on top land area
Rods		
Rod Bushings		normal to no wear
Rod Bearings		still in specs for reuse guidelines but do show more than normal marking - somewhat like they see when coolant gets in the oil

Pumps		
Lube Pump		Some wear, normal
Water Pump		OK
Fuel Lift Pump		Rust on strainer bolt, slight sediment on screen
Damper		Normal
Seals		
Front Crank Seal		Normal - to less seepage
Rear Crank Seal		Normal - to some seepage from rear main
Gears		
Cam		Normal
Crank		Normal
Fuel Pump		Normal
Injection Pump		#6 had heavy engine oil surrounding the lower end indicating leakage between the governor and the pump #1 - had a bad upper o-ring; in removing the other barrels no other bad o-ring was found They all have a slight rusting of the barrel
Fuel Line Brackets		
Fuel Lines		
Shut Down Solenoid		
Shut Down Solenoid Bracket		
Exhaust Manifold		
Exhaust Manifold		OK
Turbo		Good, no excess end play, tight
Exhaust Gasket		Good
Intake		
Grid Heater		OK - looks good
Other		
Oil Cooler		
Thermostat		
Belt Tensioner		

Yellowstone Park Dodge
Cummins 5.9L B Engine
Teardown Measurements
8 October 1998

Page	Name	Maximum	Minimum	Cylinder (all values given in inches)					
				1	2	3	4	5	6
9-128 9-144	Cylinder bore	102.116 mm (4.0203 inch)	102.0 mm (4.0157 inch)	4.0160	4.0164	4.0164	4.0166	4.0166	4.0162
	Cylinder Out-of round	0.038 mm (0.0015 inch)		0.0001	0.0002	0.0005	0.0006	0.0006	0.0002
	Cylinder Taper	0.76 mm (0.003 inch)		0.0011	0.0006	0.0007	0.0000	0.0012	0.0010
9-131	Intake Valve Stem Diameter	7.960 mm (0.3134 inch)	7.935 mm (0.3126 inch)	0.3132	0.3133	0.3132	0.3131	0.3132	0.3132
	Intake Valve Guides - bore	8.089 mm (0.3185 inch)	8.019 mm (0.3157 inch)	0.3164	0.3166	0.3167	0.3165	0.3166	0.3168
9-131	Exhaust Valve Stem Diameter	7.960 mm (0.3134 inch)	7.935 mm (0.3126 inch)	0.3132	0.3133	0.3132	0.3133	0.3134	0.3133
	Exhaust Valve Guides - bore	8.089 mm (0.3185 inch)	8.019 mm (0.3157 inch)	0.3168	0.3162	0.3166	0.3166	0.3170	0.3166
9-142	Camshaft journal		53.962 mm (2.1245 inch)	2.1258	2.1259	2.1260	2.1261	2.1260	2.1260
	Valve Lobe Height - Intake		47.040 mm (1.852 inch)	1.8781	1.8781	1.8776	1.8765	1.8791	1.8784
	Valve Lobe Height - Exhaust		46.770 mm (1.841 inch)	1.8517	1.8517	1.8510	1.8492	1.8498	1.8505
	Lift Pump Lobe Diameter		35.500 mm (1.398 inch)	1.4159					
	Camshaft Bore Diameter	54.133 mm (2.1312 inch)		2.1311	2.1300	2.1301	2.1298	2.1294	2.1296
	Tappet Bore Diameter - Intake	16.055 mm (0.632 inch)		0.6285	0.6270	0.6287	0.6286	0.6286	0.6281
	Tappet Bore Diameter -	16.055 mm (0.632 inch)		0.6300	0.6294	0.6295	0.6296	0.6297	0.6296

	Exhaust								
9-149	Piston Skirt		101.823 mm (4.0088 inch)	4.0107	4.0103	4.0106	4.0105	4.0105	4.0103
	Piston Pin Diameter		39.990 mm (1.5744 inch)	1.5745	1.5745	1.5745	1.5745	1.5745	1.5745
	Piston Pin bore	40.025 mm (1.5758 inch)		1.5747	1.5749	1.5748	1.5750	1.5748	1.5749
	Connecting rod pin bore	40.042 mm (1.5764 inch)		1.5748	1.5750	1.5748	1.5750	1.5751	1.5751
9-149	Connecting rod bore (with bearings installed and bolts tightened to 100 N*m (73 ft. lbs) torque		record smaller diameter	2.7182	2.7191	2.7190	2.7202	2.7190	2.7198
9-150/156	Crankshaft Rod journal	69.013 mm (2.717 inch)	68.962 mm (2.715 inch)	2.7178	2.7174	2.7175	2.7167	2.7166	2.7179
	Out of round	0.050 mm (0.002 inch)		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	Taper	0.013 mm (0.0005 inch)		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	Bearing Clearance (calculated by difference)	0.089 mm (0.0035 inch)		0.0012	0.0017	0.0015	0.0035	0.0024	0.0019
Position each ring in the cylinder and use a piston to square it with the bore at a depth of 89.0 mm (3.5 inch) and then measure the ring end gap									
9-152	Top	0.700 mm (0.0275 inch)	0.400 mm (0.0160 inch)	0.020	0.021	0.021	0.020	0.021	0.021
	Intermediate	0.550 mm (0.0215 inch)	0.250 mm (0.0100 inch)	0.013	0.013	0.017	0.017	0.017	0.017
	Oil Control	0.550 mm (0.0215 inch)	0.250 mm (0.0100 inch)	0.012	0.015	0.013	0.015	0.014	0.014
9-154	Crankshaft Main Journals	83.013 mm (3.2682 inch)	82.962 mm (3.2662 inch)	3.2672	3.2671	3.2670	3.2671	3.2672	3.2670

Table E-1. Engine Teardown Inspection Notes.

Component	Condition
Cylinder Head	
Injectors	Less carbon than usual on all parts, less carbon than would be expected from diesel
Valves	Normal – do not need regrinding, deposits very low
Cam Shaft	Slight pitting on 2 lobes, others not a problem. normal wear
Cam Thrust Plate	Slight wear around outer edges – no wear on inner edge
Tappets	Some very slight pitting to match cam
Head Gasket	Good, no leakage, no coolant, no blow across
Block	
Main Bearings	Very good, no wear
Crankshaft	Slight seep of oil from rear main, slightly more than front. Exceptionally good journal condition, slight grooving at seals
Pistons	Clean, some deposits on top land
Rings	
Top	Even wear in center, no contact on edges, 10% each
2nd	25% face contact, clean
Oil	No apparent wear
Piston pins	No wear, normal
Liners	Honing marks apparent throughout, slight deposit on top land area
Rods	
Rod Bushings	Normal to no wear
Rod Bearings	Still within specs for reuse guidelines, but do show more than normal marking – somewhat like what is seen when coolant gets in the oil
Pumps	
Lube Pump	Some wear, normal
Fuel Lift Pump	Rust on strainer bolt, slight sediment on screen
Damper	Normal
Seals	
Front Crank Seal	Normal to less seepage than normal
Rear Crank Seal	Normal to some seepage from rear main
Injection Pump	#6 had heavy engine oil surrounding the lower end indicating leakage between the governor and the pump. #1 had a bad upper o-ring. In removing the other barrels, no other bad o-ring was found. All have a slight rusting of the barrel.
Exhaust Manifold	
Turbo	Good, no excess end play, tight

Appendix F

Bosch Fuel Pump Evaluation

BOSCH	DEVELOPMENT REPORT	REPORT NO. 98/40/3033
To UO/EHD	mark confidential if necessary	PROJECT NO. 5UP/0904/00

Distribution

UO/EHD1
UO/QAW1
UO/SAM6
K5EAV4-Simon
K5/ERR2-Schneider
K5/EMF3-Grieshaber
K5/ERR2-Falci

Pages:
Enclosures:

Engineer:
V. Fabis

Date / Sign.
1/5/98 /
/
/

Tel. Ext. 5697

Checked:

Date 9/21/98 / Sign.

Report copy to customer:

Yes/No

Dev. Dept.:

Date / Sign.
9/25/98

PRODUCT: P7100 + RQVK
CUSTOMER: All / P7100
YEAR/QTR: 98/III

KEYWORDS
Field Test
Rapeseed Ethyl Esters

Subject:
Evaluation of field test pumps.

Scope:
The below listed pump was run for 92,838 miles using an alternative fuel source called Rapeseed Ethyl Esters (REE), see attachment 1 for fuel specific properties.

- Pump: 0 402 736 841 Pump SN: 46900 02018
- Application: 1995 Dodge ¾ ton pick-up truck
- Engine: Cummins 5.9L turbo Diesel – 175HP @ 2500 ERPM

Evaluation:
The pump in as received condition had one of the base plugs damaged. The pump was not run as received only disassembled and inspected. The damage to the base was done after the pump was removed from the engine, not as a result of a pump failure.

+ Visual inspection of pump hydraulic components:
- *Elements*: All plungers show some fuel deposits. See attachment 2 for photos.
  All moved freely in the barrels.
  No cavitation or erosion on any of the elements.

- *Delivery Valves*: All valves moved freely in valve bodies.
  Some fuel deposits on the valves.
  No cavitation on delivery valves.

- *Delivery Valve Springs*: All springs were measured and found to be within specification.
  No fuel deposits found on springs.

- *Delivery Valve Holders*: All snubber valves are functioning.
  Hydraulic flow was not checked.
  No fuel deposits in DVH.

- *Barrel O-rings*: Cylinder 1 lower barrel o-rings are damaged. See attachment 3 and 4 for photos.
  The bottom barrel o-ring damage is most likely from assembly.
  All other o-rings are visually in good condition.

- *Nozzle Holder Assemblies*: See report 98/43/3034 for detailed analysis.

+ Visual Inspection of Pump Components:
- Camshaft: Very good condition, polish marks on lobes.
- Bearings: Very good condition
- Roller tappets: Very good condition, polishing on rollers and roller pins.
- Pump housing: No erosion in the barrel bores.
- Overflow valve: Valve opening pressure is 1.4 bar (spec. 1.5± 0.3 bar).
  Spring shows minor wear on O.D.

+ Visual Inspection of Governor Components:
- All governor components are in good condition and show no wear.

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Conclusion:

- The damage to the barrel o-rings on cylinder 1 appears to be from assembly. All the o-rings will be sent for complete material analysis.
- The fuel deposits on the plungers are not severe enough to cause stickiness. Further testing needs to be done to insure fuel deposit will not get worse as higher mileages are achieved.
- The pump components showed minimal wear using this fuel. However, actual full load endurance test and high mileage field test (over 300K miles) would give a better indication of long term affects with Rapeseed Ethyl Esters fuel.

Recommendation:

- The o-rings will be sent to KS/ERR2-Falci for material evaluation.
- The pump will be reassembled / recalibrated and returned to Technology and Engineering Management / Biomass Energy Systems.

Date: 14 Sep 98

Engineer: V. Falci

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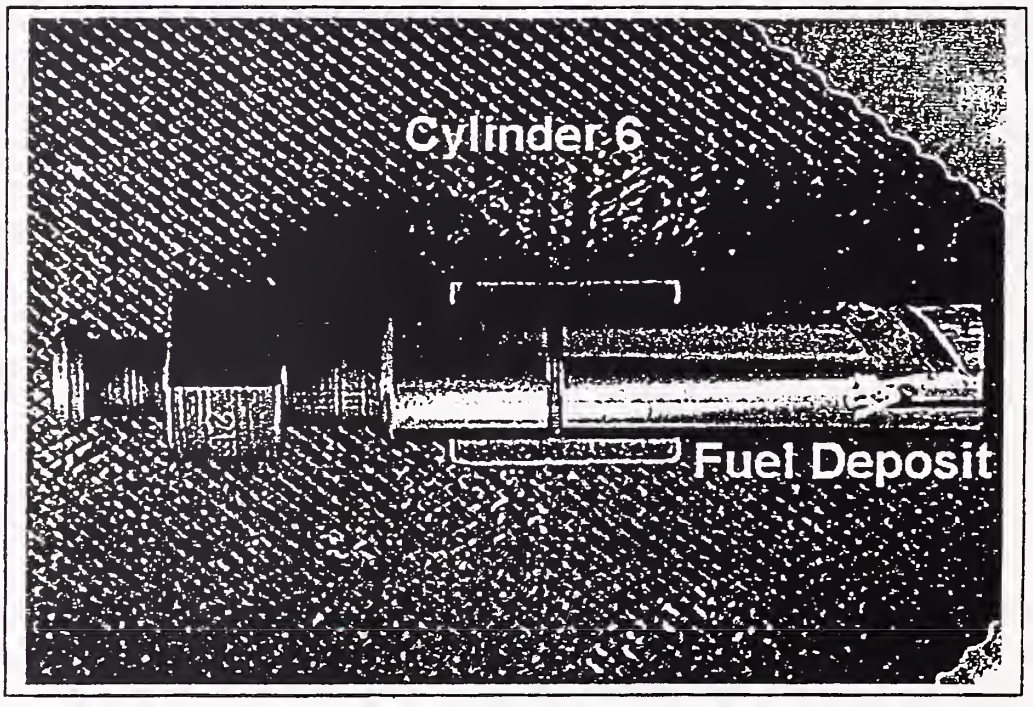
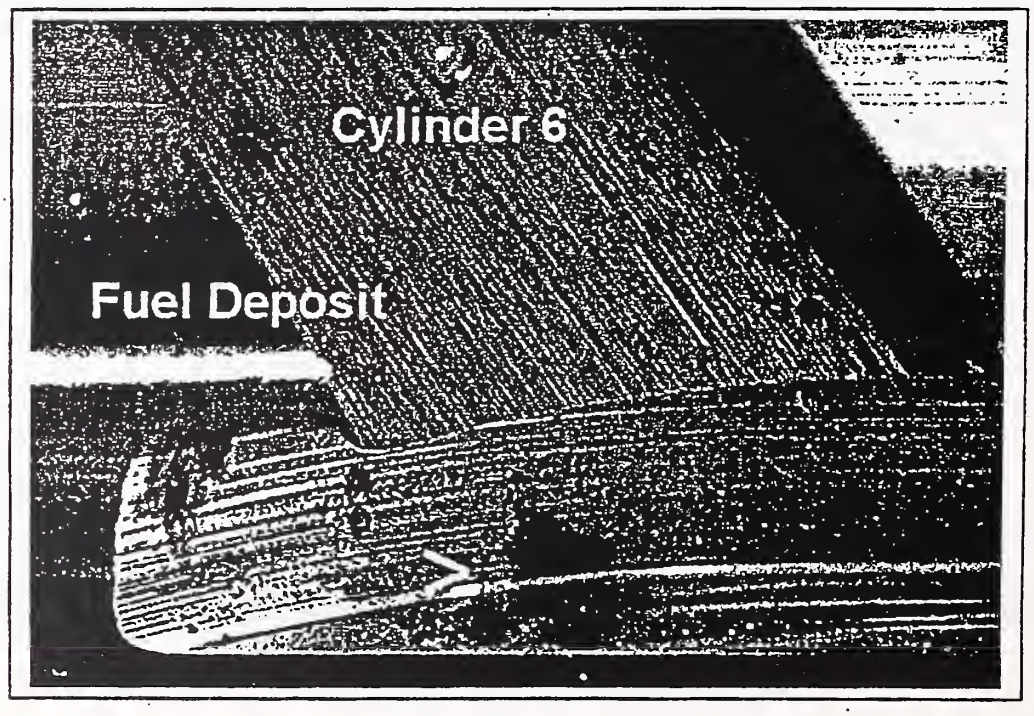
Fuel Deposits on Plungers
Pump: 0 402 736 841, SN: 46900 02018
Date: 08 Sep 98

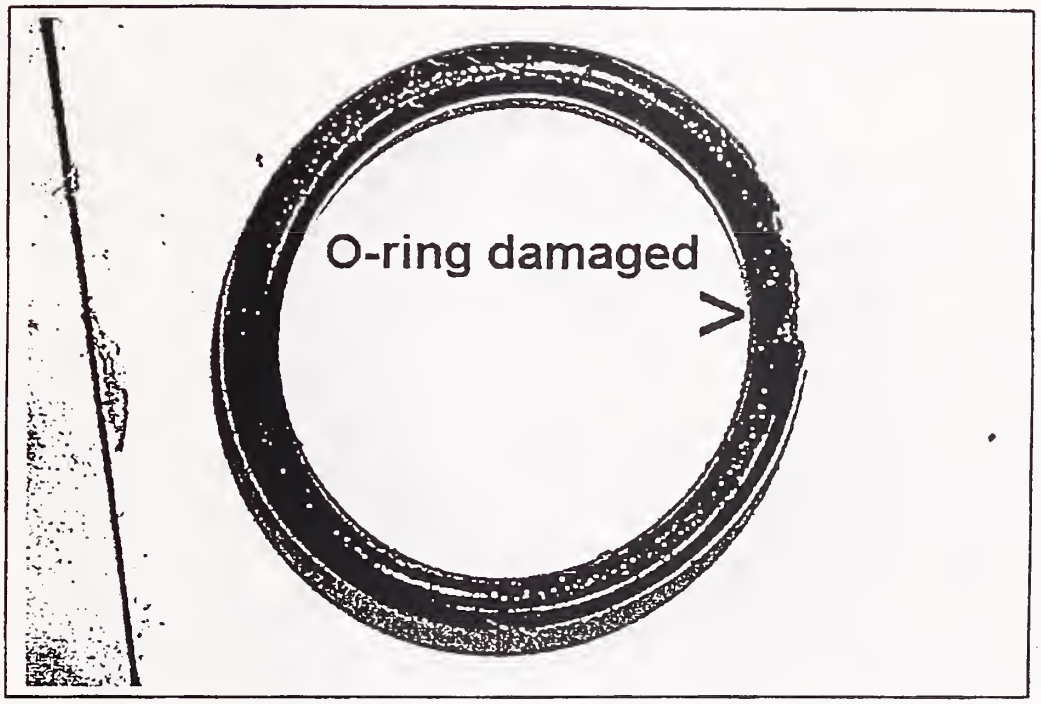
Attachment 2
BOSCH

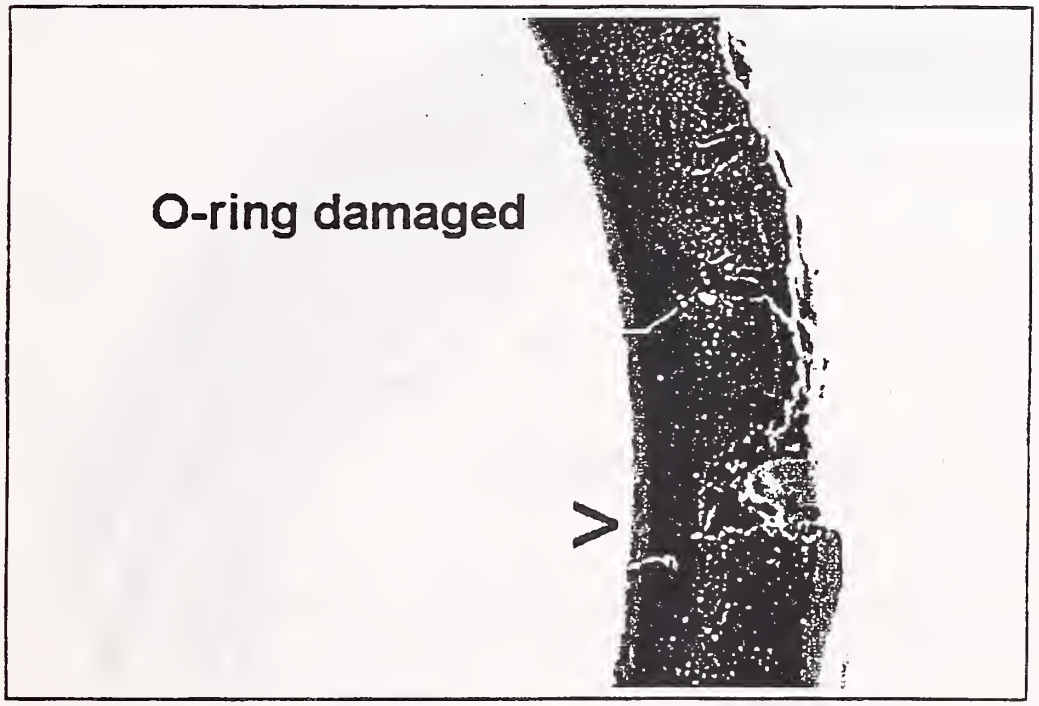




Cylinder 1 barrel o-ring: 1 410 210 014
Pump: 0 402 736 841, SN: 46900 02018
Date: 08 Sep 98

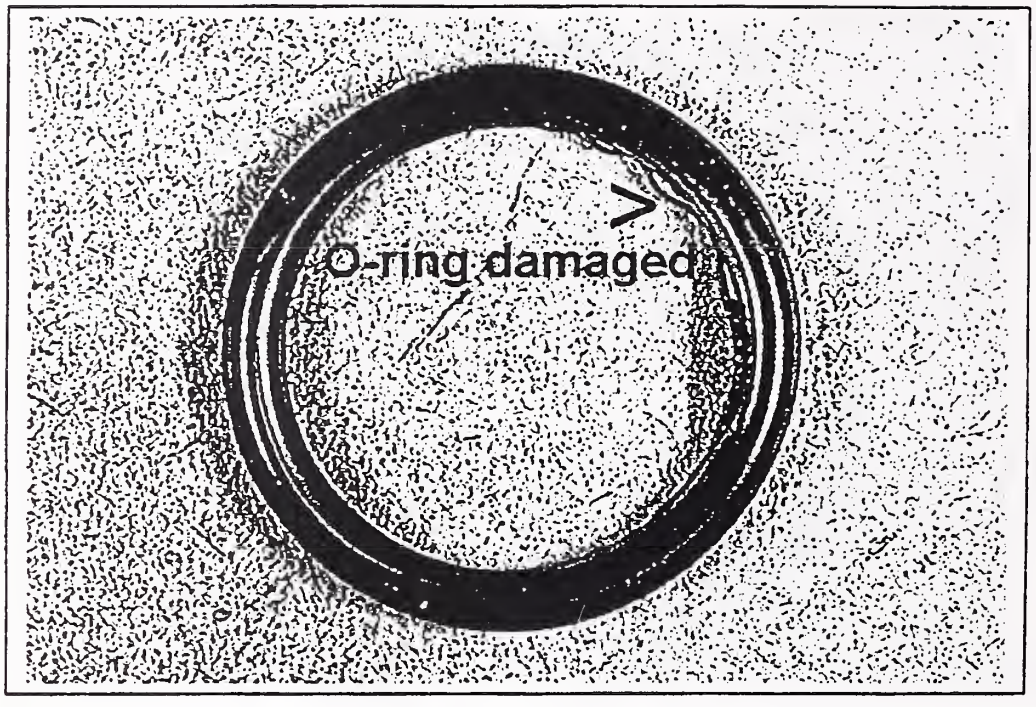
Attachment 3
BOSCH

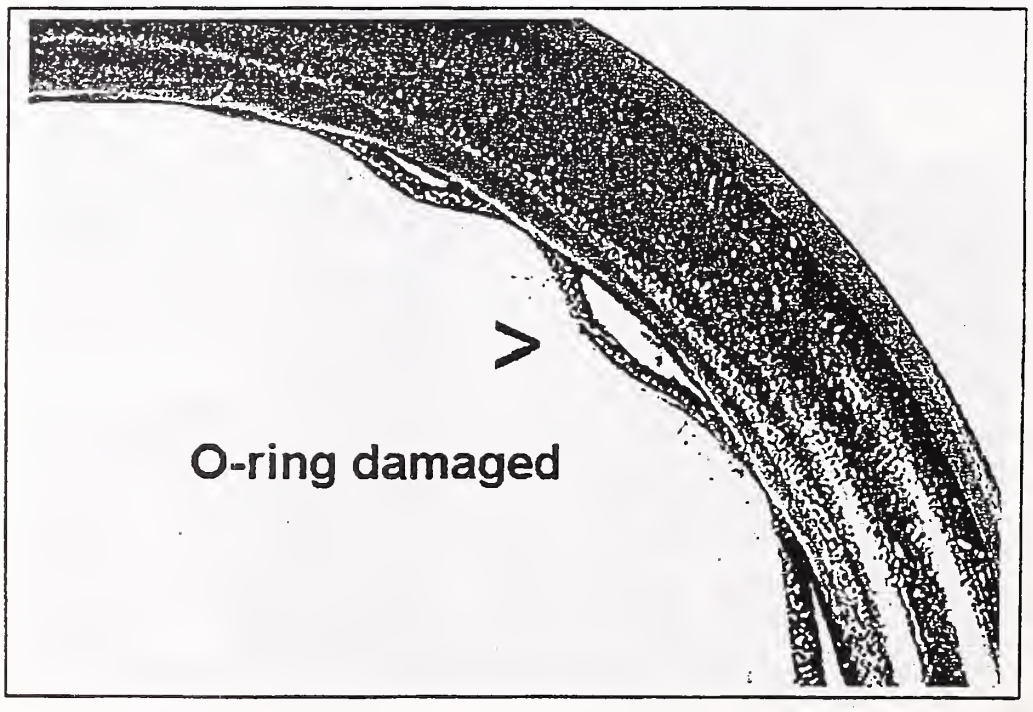




Cylinder 1 lower barrel o-ring: 1 410 210 014
Pump: 0 402 736 841, SN: 46900 02018
Date: 14 Sep 98

Attachment 4
BOSCH





BOSCH	DEVELOPMENT REPORT	REPORT NO. 98/43/3034
To UO/EHD	mark confidential if necessary	PROJECT NO. 5UP/0904/00

Distribution

UO/EHD1
UO/QAW1
UO/SAM6
K5EAV4-Simon
K5/ERR2-Schneider
K5/EMF3-Grieshaber
K5/ERR2-Falci
K5/EHD

Pages:
Enclosures:

Engineer:
V. Fabis

Date / Sign.
9/21/98 / V. Fabis
/
/

Tel. Ext. 5697

Checked:

Date / Sign.
9/24/98 /

Report copy to customer:

Yes/No

Dev. Dept.:

Date / Sign.
9/25/98
Blue

PRODUCT: NHA
CUSTOMER: All / P7100
YEAR/QTR: 98/III

KEYWORDS
Field Test
Rapeseed Ethyl Esters

Subject:
Evaluation of field test nozzle holder assemblies.

Scope:
The below listed NHAs was run for 92,838 miles using an alternative fuel source called Rapeseed Ethyl Esters (REE), see attachment 1 for fuel specific properties.

- NHA : 0 432 133 860 Nozzle: DSLA145P464, 0 433 175 078
- Pump: 0 402 736 841 Pump SN: 4690002018
- Application: 1995 Dodge ¾ ton pick-up truck
- Engine: Cummins 5.9L turbo Diesel – 175HP @ 2500 ERPM

Evaluation:
+ See Report 98/40/3033 for pump analysis.

+ Nozzle opening pressure was checked in as received condition. VOP ranged from 239-248 bar, (setting spec. 260 + 10 bar). See attachment 2 for actual values. All spray holes were open.

+ Nozzle hydraulic flow was checked in as received condition. Flow ranged from 642-661 cc/30 sec. (manufacturing spec. 618-662 cc/30sec.). See attachment 2 for actual values.

+ *Visual Inspection*
- The nozzles have some carbon deposits around the holes. See attachment 3 for photo.
- Needle seat area: Minor polishing
- Needle guide: Minor polishing
- Pressure spring: Wear marks on shim end.
- Pressure shims: Wear marks on spring end.No fuel deposits seen on internal parts.
- No fuel deposits seen on internal parts.

Conclusion:
- The opening pressure drop is normal for this mileage range.
- There is no abnormal wear on any of the components. However, actual full load endurance test and high mileage field test (over 300K miles) would give a better indication of long term affects with Rapeseed Ethyl Esters fuel.
- The carbon build up on the nozzles has not affected the spray holes at this time. This will need to be further evaluated on high mileage samples to insure it does not worsen and cause nozzle hole plugging.

Recommendation:
The nozzle holder assemblies will be reassembled / reset and returned to Technology and Engineering Management / Biomass Energy.

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BOSCH | NOZZLE TEST SHEET 468 | PROJECT # 1

NOZZLE DESIGNATION: DSLA 145 P 464 MFD 467 FC 060

NOZZLE DRAWING # RBUO _____ RB _____

TEST NOZZLE HOLDER: TEST BENCH STANDARD S-TYPE Y 430 H00 280 ☐
KDAL 59 P 6 MFD 469 " FC 939 Cust. 6818 P-TYPE Y 430 H00 252 ☐
" " " NEEDLE LIFT Y 430 S00 098 ☐
ENGINE N.- HOLDER # _____ ☐

SACHOLE: _____ DIA. x _____ LENGTH [MM]
SACHOLE CONFIGURATION: CYLINDRICAL ☐, TAPERED ☐, SACLESS ☐
VALVE TO SEAT RATIO: _____ x _____ [MM]
NEEDLE LIFT: _____ [MM]
NEEDLE CLEARANCE: _____ ROTA [L/h]
SPRAYHOLES: # _____ x _____ DIA. x _____ LENGTH [MM]

NOZZLE NUMBER		LOCATION OF SPRAY HOLES ∢ Ψ AND Ψ										HYDR. FLOW WITH NEEDLE AT SPEC LIFT 30 SEC 100 BAR [CC]		ROTA FLOW [L/h]
		1	2	3	4	5	6	7	8	9	10	1	NEEDLE LIFT MM	
1	H	MFD										652		
	V	467												
2	H											644		
	V													
3	H		HYDRAULIC FLOW SPEC 618.. 662 cm³/30 sec. at 100 bar									661		
	V													
4	H											642		
	V													
5	H											648		
	V													
6	H											660		
	V													
	H													
	V													
	H													
	V													

NOZZLE NUMBER	OPENING PRESSURE bar									
	1	2	3	4	5	6	7	8	9	10
1	244									
2	239									
3	242		SPEC 260...270 bar							
4	248									
5	245									
6	244									

BAROM. PRESS.: _____
ROOM TEMP.: _____

WORK ORDER NO: _____

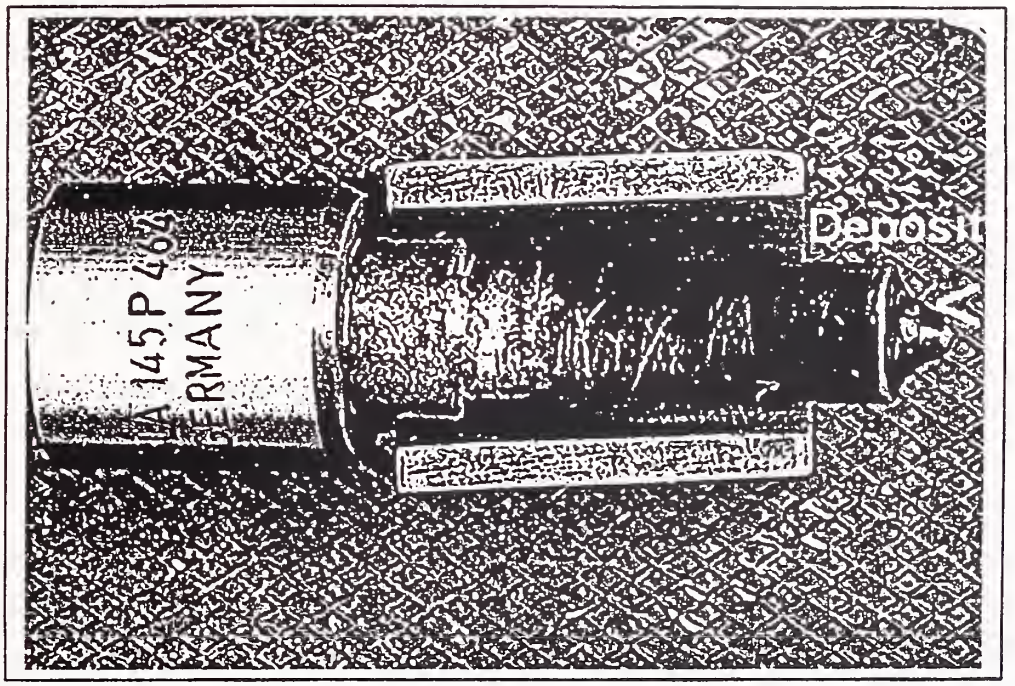
DK
TESTER

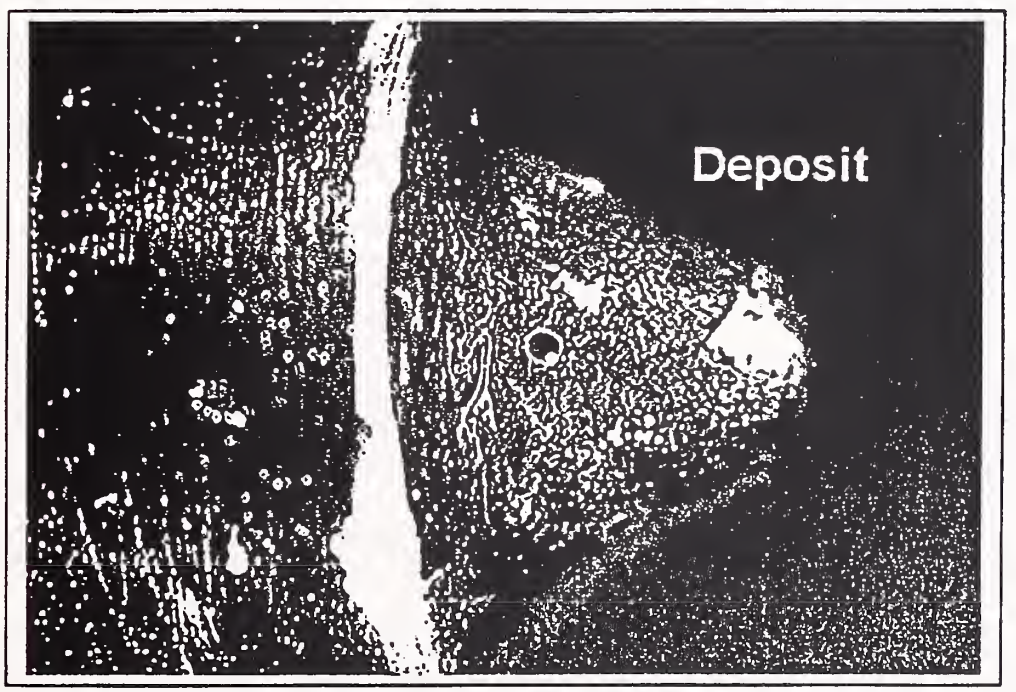
9/14/98
DATE

UO/EDI3-F 0327 SHEET 1 OF 2

Cylinder 3 nozzle: DSLA 145P464
Pump: 0 402 736 841, SN: 46900 02018
Date: 15 Sep 98

Attachment 3
BOSCH





Appendix G

Pacific Northwest and Alaska
Regional Biomass Energy Program
Montana Project Summary Sheet

Pacific Northwest and Alaska
Regional Biomass Energy Program
Montana Project Summary Sheet

1. **Title:** ***Pilot Demonstration of Biodiesel in Tourism-Related Transportation: A Truck in the Park***

2. **Brief Description:** DEQ is spearheading a project to demonstrate biodiesel use in Yellowstone National Park (YNP). With visitation increasing yearly, there is a need for more efficient transportation, such as buses, and reduced pollution, odors, and smoke caused by tourism transportation. Rapeseed ethyl ester (REE) could be at least part of the remedy for pollution generated by motor vehicles in Yellowstone. REE is produced from rapeseed oil reacted with ethanol that is made from potato waste generated by the food processing industry. Yellowstone offers an opportunity to demonstrate this low emission, biodegradable fuel in an environmentally sensitive and extremely cold area. Such areas may prove to be a near-term niche market for this and similar bio-based fuels.

3. **Grantee:** Montana Department of Environmental Quality, Pollution Prevention Bureau, 1520 East Sixth Avenue, P. O. Box 200901, Helena, MT 59620-0901.
   Contact: Howard E. Haines, Bioenergy Engineering Specialist
   Phone 406-444-6773, FAX 406-444-6836, Email hhaines@state.mt.gov

4. **Project Manager: Jeffrey W. James, Program Manager,** jeffrey.james@hq.doe.gov
   U. S. Department of Energy Seattle Support Office
   800 Fifth Avenue, Suite 3950, Seattle, WA 98104 Phone 206-553-2079, FAX 206-553-2200
   Identification No: **DE-FG51-94R020493**, DEQ CNo. 780006 formerly EDG- 95-7562, file TiPP.100

5. **Estimated total cost:** $341,294 DOE **Regional Program Funds: $111,102**

6. **Cost Sharing and Project Partners:** $230,619
   Montana Department of Environmental Quality (DEQ): project design and lead ($50,000)
   U. S. Department of Interior, National Park Service, Yellowstone National Park (NPS), truck equipment, lube oil, fuel storage facilities, canola ethyl ester (CEE) and operator (in-kind) + $35,419
   Wyoming Department of Commerce, Energy Office, emissions testing ($30,000)
   Dodge Truck of Chrysler Corporation [vehicle + technical oversight + in-kind]
   Cummins Engine Company (engine + technical support)
   Cummins Intermountain Distributor, Pocatello **ID**
   J.R. Simplot Company, Boise, ID (ethanol and catalyst for biodiesel)
   Koch Agricultural Services Company, Great Falls, MT [rapeseed oil + shipping)
   Tractor & Equipment Company (T & E), Billings, Montana [performance testing)
   University of Idaho (UI), Agricultural Engineering Department, (fuel, emissions, performance test analysis, reduced indirect)
   McGreggor Company [biodiesel and feedstock storage]
   University of California, Davis, Environmental Toxicology Department [PAH evaluation]

7. **Expanded Description:** The "Truck in the Park" Project was designed with two purposes: to define a market for biodiesel and to provide data on emissions and performance that could be used by land managers, regulators, and providers of commercial tourism transportation. This project was a first-step to reduce environmental impacts resulting from diesel fuel use in the tourism industry. The Montana Department of Environmental Quality (DEQ, successor to the Department of Natural Resources and Conservation) in cooperation with the National Park Service (**NPS**) and Dodge Truck Division of the Chrysler Corporation operated a 1995 ¾ ton 4x4 diesel truck fueled by 100 percent rapeseed ethyl ester produced by the University of Idaho (**UI**) and private cooperators. Basically, the project placed an unaltered diesel pickup truck into service in

Yellowstone National Park, fueled this truck with 100 percent rapeseed ethyl ester, and monitored performance and emissions. Data were collected to determine the reliability, benefits, and costs of using biodiesel in Yellowstone National Park and the surrounding region. The project included fuel characterization, detailed performance and emissions tests before and after (approximately) 149,408 km (92,838 miles) (using EPA protocols), and other quality control testing to document benefits and costs.

8. **Needs Addressed:** Each year about 3 million people visit Yellowstone National Park. The nearly 900,000 automobiles they use to travel to the Park burn thousands of gallons of fuel and produce tons of air pollution, endangering the clear air and water that people expect to see during their visit to the Park. The air in the Park meets EPA air standards, but not always the visitors' expectations.

With visitation increasing steadily over the last several decades, concern has arisen because of increasing congestion on park roads and the threat of increased pollution. One possible solution is to limit visitation, an option not likely to please the members of the public who may not be able to arrange their visit to the park when there are openings. Limiting visitation also is not favored by park concessionaires or economic interests in communities near Yellowstone.

A more desirable choice is to reduce congestion by encouraging use of high occupancy vehicles, such as buses, and by reducing the amount of pollution produced by each vehicle. One way of doing this is to use fuel that produces less pollution when burned in a conventional diesel engine and has exhaust that is less obnoxious to riders and visitors. Vegetable oil can be processed into a diesel fuel--a biodiesel--that produces less pollution than conventional diesel fuel. Exhaust emissions from these biodiesels smell less unpleasant than conventional diesel exhaust. Conventional diesel fuel also has other characteristics that are undesirable in areas valued for environmental cleanliness. These include toxicity and low biodegradability. Reformulated diesel fuel, intended to meet air emission requirements, is not enough of an improvement to meet the requirements of places like Yellowstone.

Rapeseed ethyl ester (REE) biofuel is a regional development by the University of Idaho (UI) from resources in Montana and Idaho. UI research has shown that REE has increased biodegradability and reduced emissions, odor, and smoke compared to petroleum diesel fuel. REE is at the stage of development where a higher value market, such as this tourist-related application, is the next logical step on the way to commercialization.

9. **Project Objectives:**

- Assist NPS and private industry develop options for reducing environmental degradation without adversely impacting visitation and associated industries;
- Support development of a process to convert food processing waste oil to an environmentally friendly transportation fuel, reducing both dependence upon imported petroleum and the impact on the environment;
- Encourage the development, production, and use of this biofuel within the region;
- Make the first step toward use of low odor, low smoke fuels for tourism leading to use in buses;
- Determine the impacts, benefits, and results from using biodiesel under variable conditions including high elevations and low temperatures; and
- Link the tourism industry with agriculture and energy.

10. **Approach:** To help commercialize REE, this project:

- Introduces public and private operators to rapeseed ethyl ester biodiesel as an alternate fuel or blend with regular diesel in environmentally sensitive applications;
- Develops data to support decisions regarding these fuels in areas with economies based on tourism, such as YNP.

To accomplish this, the National Park Service is operating a 1995 Dodge 3/4 ton 4X4 pickup with 5.9 liter Cummins diesel engine, supplied by Dodge Truck. The truck runs under normal operating conditions as a

maintenance inspection vehicle in YNP. No modifications are made to the truck's engine or fuel system. The truck uses 100 percent REE as fuel to develop data for warranty purposes. The demonstration includes normal service and maintenance, and periodic performance and emissions testing to determine if there is any degradation in emissions or performance caused by the fuel. Initial tests were conducted to determine the safety of the fuel and its use relative to the area's wildlife.

This project is in an area that brings humans and wildlife such as bears into close proximity. REE is a vegetable oil derivative that smells similar to oil used in cooking food. The exhaust from a diesel engine fueled by REE smells like a French fry cooker, and may attract bears if the bears in the area connect the scent to a food reward. Attracting bears to vehicles operated by humans should be avoided. A bear attractant analysis was conducted, first to determine if bears are attracted by the scent of biodiesel more so than they are to regular petroleum products, and second to identify if a blend of petroleum diesel with biodiesel reduced the attraction. These data were needed for other users located in environmentally sensitive applications. The demonstration concluded with a detailed emissions test followed by disassembly and inspection of the engine and low pressure fuel systems by Cummins Intermountain Distributor and Bosch.

11. **Major Milestones: Term,** October 15, 1994 through December 30, 1998
Bear attractant analysis (completed March 1995, report November 1995)
Establish dedicated biodiesel fueling station at YNP (12/5/94)
Vehicle acquisition and preparation (Delivered 2/7/95, markings 3/10/95)
Biodiesel fuel delivery, operational demonstration (4/15/95 to 11/30/96)
Engine oil analysis (every change)
Engine performance analysis (start, middle, and end of each year, 3/7 & 8/17/95)
Emissions tests (Dynamometer Transient Conditions Emission Tests 3/20-24/95 and 5/26-29/98)
Engine disassembly and inspection, Cummins Engine Company, July 1998.
Reporting, information transfer, presentations

12. **Results:** (Also see item 11. Major Milestones, above)

Abstract

The "Truck in the Park" Project was designed with two purposes: to define a market for biodiesel and to provide data on emissions and performance that could be used by land managers, regulators, and providers of commercial tourism transportation. This project was a first-step to reduce environmental impacts resulting from diesel fuel use in the tourism industry. Basically, the project placed an unaltered diesel pickup truck into service in Yellowstone National Park, fueled this truck with 100 percent rapeseed ethyl ester, and monitored performance and emissions. Data were collected to determine the reliability, benefits, and costs of using biodiesel in Yellowstone National Park and the surrounding region. The project included fuel characterization, detailed performance and emissions tests before and after (approximately) 149,408 km (92,838 miles) (using EPA protocols), and other quality control testing to document benefits and costs. The technical data and results of this demonstration are documented in a number of papers listed below. From this demonstration, we can conclude that:

1. The effects of biodiesel on criteria emissions with and without the catalytic converter were unaffected over the course of time, and that no new compounds are generated in blends of biodiesel with conventional diesel. Air toxics are significantly reduced by increasing the amount of biodiesel in a blend. Overall, hydrocarbons, carbon monoxide were reduced by the use of biodiesel. Oxides of nitrogen were either slightly reduced or unaffected by the use of 100 percent biodiesel, and particulate matter was slightly increased or unaffected;
2. The project developed data for use in modeling air quality so the impacts can be assessed before a large scale conversion is implemented;
3. Biodiesel or a blend may be the fuel of choice for restricted or poor air dispersion conditions. Tests also showed that the sweet odor of biodiesel exhaust does not attract bears, which was a concern to Park and land management officials.
4. Operation during two Yellowstone winters showed that normal cold-weather diesel modifications were sufficient to enable use of biodiesel in cold weather operations. These included engine coolant, an engine block heater, battery heaters, an external (electric, magnetic) fuel tank heater, and a heating loop to the slip tank. The truck failed to run on only one occasion with a daytime temperature of -38.3E C (-37EF),

a time when most things were only running for cover). However, biodiesel in Europe does use a biodegradable cold flow plug point additive for cold climate operations.

5. The benefits of biodiesel include reduced toxicity, emissions, smoke, unpleasant odor, and increased safety and biodegradability. Two challenges yet remain: availability and cost. For this project, the refueling infrastructure and availability was carried in the bed of the truck, somewhat reducing the truck=s usefulness for work. The cost factor was overcome in part by the generous contributions from our many sponsors.

Status

From February 7, 1995 through July 20, 1998, NPS personnel traveled more than 92,838 miles in the truck. The Truck was highlighted at the workshop: Greening of Yellowstone and Beyond: Preserving and Protecting Our Future, Montana State University, Bozeman, May 14, 1998. NPS continued regular maintenance without any surmountable problems. The final detailed emissions test is being conducted at the Los Angeles County Metropolitan Transportation Authority Emissions Test Facility in Los Angeles, May 26 through 29, 1998.

Upon completion of those tests, the truck had a final dynamometer test run at Western States Caterpillar, Spokane Washington, the week of June 1. As part of the technical investigation, the Cummins Engine Company's Intermountain Distributor in Pocatello, Idaho, dis-assembled the engine for inspection. This was due to the project's time limits which was about a sixth of the engine's normal a service life. In early July 1998, the inspectors found the engine was cleaner than engines of similar use fueled by diesel fuel. All parts were as good or better for than those from the engines fueled by conventional diesel. Bosch, manufacturer of the fuel injector pump, inspected the fuel pump for wear. They found no unusual wear attributable to the fuel, and found that one o-ring was probably damaged during initial construction. They reassembled the pump, and would like to see it after 300,000 miles of use. In summary, the engine was cleaner than if diesel had been used, and engine part wear was as good as or better than if diesel fuel had been used.

The truck was donated by Dodge Truck in Michigan to Yellowstone's historic vehicle collection. Park Service staff have plans for a more accessible display location to be built on the site of the old Yellowstone Park Company Transportation Building that burned in 1926. Funding for the building and transportation center is still a critical issue. The truck is the first alternate fueled vehicle in the nation's first national park.

A final report with the results of the emission test, a summary of the project, and a summary and comparison (with other University of Idaho truck engines) of the inspection findings will be available by mid-1999.

As a result of this project and the recent Greening of Yellowstone Workshop, the Park Service has indicated it would like to expand the use of biodiesel in its fleet. Several activities are proposed, including its use in a winter snow groomer, concessionaire buses, and in marine equipment. The main problems are a lack of fuel availability and cost.

Reports, Papers, Other:

Biel, M. J., H. E. Hoekstra, and K. A. Gunther. November 1995. **Bear Attractant Test of Alternate Fuel Rapeseed Ethyl Ester**. Bear Management Office, Yellowstone Center for Resources, National Park Service. Yellowstone National Park, Wyoming.

Haines, H. August 18, 1995. **Status Report on the Truck in the Park Demonstration Project**. Montana Department of Environmental Quality, Helena, Montana.

Haines, H., and J. Evanoff. December 8, 1998. Environmental and Regulatory Benefits Derived from the Truck in the Park Biodiesel Emissions Testing and Demonstration in Yellowstone National Park. Montana Department of Environmental Quality. Helena, Montana.
http://www.deq.state.mt.us/ppa/trkinprk.pdf or http://www.nps.gov/renew/yellbio.htm

Kado, N. Y., P. A. Kuzmicky, H. E. Haines, and R. A. Okamoto. November 1996. **Chemical and Bioassay Analyses of Diesel and Biodiesel Particulate Matter: Pilot Study**, EDG-95-7561.

Montana Department of Environmental Quality. Helena, Montana.

Peterson, C., S. Beck, C. Chase, H. Haines, D. Reece, and J. Thompson. August 22, 1995. **Producing biodiesel for the Truck in thePark Project.** Biomass Conference of the Americas, Portland, Oregon.

Peterson, C., C. Chase, H. Haines, D. Reece. October 16, 1995. **Emissions Testing at LA-MTA for the Truck in the Park Project: Interim Report EDG-95-7562, TiPP.106.10.**Montana Department of Environmental Quality. Helena, Montana.

Peterson, C., C. Chase, H. Haines, D. Reece. November 1995. **Emissions Testing with Blends of Esters of Rapeseed Oil Fuel With and Without a Catalytic Converter: Interim Report EDG-95-7562, TiPP.106.10.** Montana Department of Environmental Quality. Helena, Montana.

Sharp, C. A., H. E. Haines. November 1996. **Emissions and Lubricants Evaluation of Rapeseed Derived Biodiesel Fuels.** EDG-93-7549, SwRI 7507. Montana Department of Environmental Quality. Helena, Montana.

13. Future Activities:. A final report due in January 1999 is being prepared on regulated emissions, the overall project, and the inspection by Dr. Peterson, University of Idaho. Dr. Norman Kado, University of California, Davis, is DEQ and others would like to see a biodiesel presence continue in the Park, and we are invetigating methods to do so.

14. Date Prepared: December 15, 1994
Date Amended: March 23, 1999

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